VOL. 5 No. 4 APRIL 1940

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

BLACK-OUT BY THE FILTER METHOD

by E. L. J. MATTHEWS and J. A. M. van LIEMPT. 535.345.6 : 628.972 : 355.585

By installing an indoor illumination system with yellow light and colouring the window-panes green a satisfactory black-out illumination can be obtained. The interior illumination is invisible at night to an observer in the air, while about 25 per cent of the daylight is able to pass through the windows whose colour is not unpleasant for the eye.

For the purposes of air raid precautions private dwellings, and in general localities where an adequate illumination is required only at certain spots, can be provided with a satisfactory "black-out illumination" with the help of "Protector" lamps, as was explained in a previous number of this periodical [1]). If, however, it is a question of making the illumination in large factory buildings, offices, shops or other buildings, where a fairly high intensity of illumination is required over the whole floor space and is to be made invisible from the outside, the problem is encountered of providing shutters or other means of cutting off the light from huge window surfaces. Such provision is not only expensive but is also open to the serious objection that the screening devices must be opened and shut daily, while the problem of ventilation is difficult to solve.

A much more elegant solution is offered by the filter method. The glass is covered with a coating of paint or coloured cellophane which transmits practically none of the light from the part of the spectrum emitted by the lamps which provide the interior illumination. This principle is illustrated by *fig. 1*, where curve A represents for example the spectral composition of the artificial illumination and curve B the spectral transmission of the coloured layer which is used to cover the glass. The coloured coating, however, transmits enough daylight to make artificial illumination unnecessary in the daytime, and it is only necessary to use artificial lighting somewhat longer at twilight. If circumstances permit, the colour of the filtered daylight can be made less pronounced for instance by leaving a small part of the window space uncoloured and screening this at night with shutters. It will be clear that in these considerations it is assumed that it is possible to avoid the radiation of light of any other colour in the rooms in question, such as that of hand lamps, open fires and welding arcs.

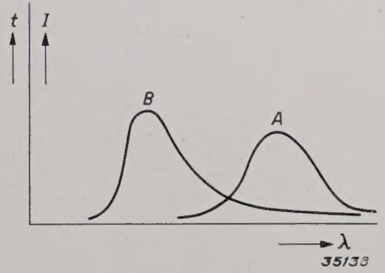

Fig. 1. For a practical black-out illumination by the filter method, curve A of the spectral distribution of intensity I of the artificial illumination, and curve B of spectral transmissibility t of the coloured windows must overlap as little as possible.

For practical purposes such a wartime illumination can be achieved with the help of lamps which radiate chiefly yellow light and if necessary by suppressing any light of shorter wave lengths. As a coating which is practically opaque for this light, use was formerly made of a type of paint which transmits well only a narrow spectral region in the blue and strongly absorbs the other components of daylight. The screening toward the outside was indeed adequate, but the effect in the daytime was anything but satisfactory. If the blue paint is applied sufficiently thick, it transmits only 4 to 5 per cent of the daylight, so that the interior illumination is insufficient and, due to the blue colour, depressing.

It has been determined experimentally that much more satisfactory results can be obtained by making the windows green in a suitable way instead of blue. It is much more pleasant to work in the green filtered daylight than in the blue, while it will appear from further considerations that sufficient screening of the yellow interior illumination can still be procured with a higher transmissibility for daylight.

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[1]) Philips techn. Rev. 4, 15, 1939.

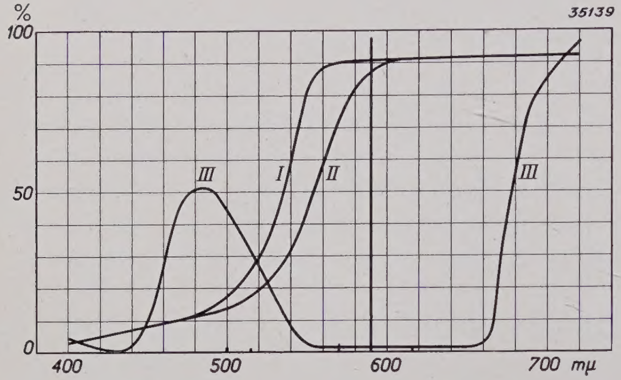

Fig. 2. Spectral transmissibility of orange "Selectiva" glass in the cold state (*I*), and at operating temperature of sodium lamps (*II*). Curve *III* gives the spectral transmissibility of clear glass covered with a green coating (paint *A* in the following) in a layer of such thickness that a total of 25 per cent of daylight is transmitted. In addition the position and relative intensity of the spectral lines of the unfiltered sodium light are also indicated.

In order to obtain this yellow artificial illumination, incandescent lamps may be used with a coloured bulb, of orange "Selectiva" glass for example, or of sodium lamps, which if desired may also be provided with an orange "Selectiva" vacuum jacket in order to remove the green and blue components which may still occur to some extent in the light of sodium lamps. The light of these orange Selectiva lamps is not unpleasant to work under, while an additional great advantage is that orange Selectiva glass is a coloured glass. With these lamps therefore there are no difficulties due to scaling off, or to lack of fastness of colour or stability toward heat, which may occur when a lamp of ordinary glass is covered with a layer of lacquer. Moreover, it will be difficult to find a suitable lacquer of the right colour.

Fig. 2 shows the variation of transmissibility of orange Selectiva glass in the cold state (*I*), and at the operating temperature of the lamp (*II*), with the wave length, while *III* shows this variation for an appropriate kind of green paint. Furthermore the relative spectral composition of natural unfiltered sodium light is represented, from which it may be seen that sodium light possesses practically no intensity, especially after passing through Selectiva glass in the spectral region which is well transmitted by the green paint. These sources of light and this paint therefore form together a suitable combination for wartime illumination. We shall now examine how the permissible level of artificial illumination and the corresponding transmissibility of the windows to be blacked out can be determined in practical cases. We must however first know the permissible brightness seen from the outside of the windows at night.

Permissible brightness of the windows

The permissible brightness of the light openings depends upon the solid angle within which the observer sees the illuminated surface. We begin with the relation already indicated by Bouma in this periodical (*fig. 3*) between this angle and the intensity of illumination E_0 produced on the eye of the observer by the radiating surfaces (assumed circular) in order to be seen from a perpendicular direction. These data may also be applied to windows surfaces which are not too elongated in form. It may be seen that for small angles of vision it is only a question of the total light intensity, while for large angles of vision it is only the brightness that is important. The values given here, however, refer to observations made in the laboratory and according to Bouma the intensities of illumination which just escape notice on a starlight night are found by multiplying the values from fig. 3 by a factor 100.

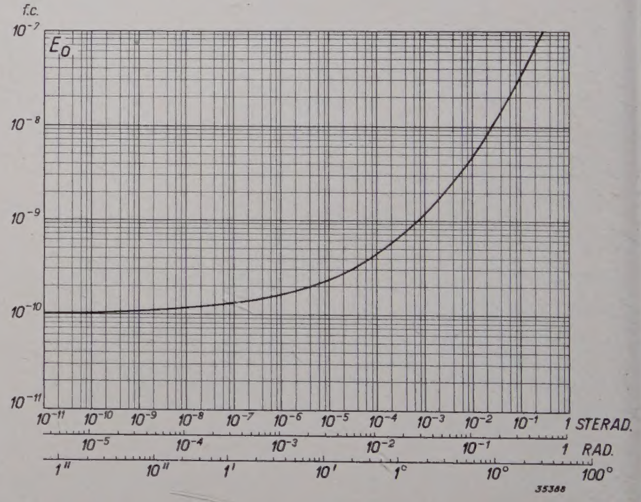

Fig. 3. Intensity of illumination E which circular radiating surfaces must produce on the eye of the observer in order to be visible in a perpendicular direction, as a function of the angle within which they are seen.

With the help of these data the relation represented in *fig. 4* between the permissible brightness B for horizontal windows vertically under the aeroplane and the area of their surface is found for different flying altitudes. For non-horizontal windows these values for the permissible brightness may be multiplied by a factor K, greater than unity.

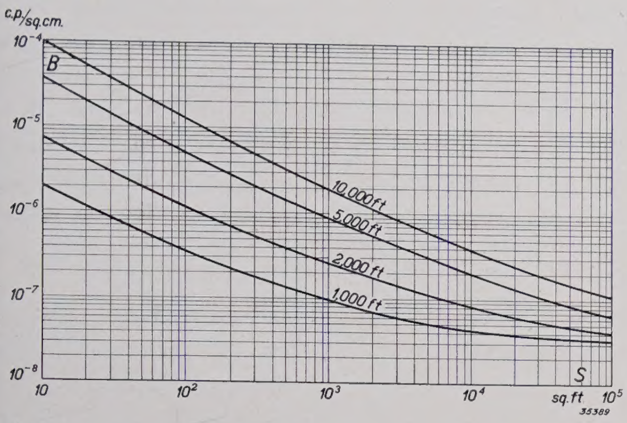

Fig. 4. The maximum permissible brightness B in c.p./sq.cm for horizontal windows with a surface area of S sq.ft is shown for different flying altitudes.

On the basis of the situation sketched in *fig. 5* we shall try to find the direction of vision making the angle α with the horizontal plane at which the greatest intensity of illumination is produced on the eye of an observer flying at a given altitude h above the earth in the vertical plane perpendicular to the window. From this the above-mentioned factor K can be calculated. The windows V make an angle β with the horizontal, and we shall assume that they radiate diffusely according to Lambert's law with a luminous intensity I perpendicular to their surface. If the observer is at a distance r at an angle α with the horizontal, he receives an intensity of illumination:

$$E = \frac{I}{r^2} \cos(\alpha + \beta - 90^\circ) = \frac{I}{r^2} \sin(\alpha + \beta) \quad . \; . \; . \quad (1)$$

Since the altitude $h = r \sin \alpha$, this becomes:

$$E = \frac{I}{h^2} \sin^2 \alpha \sin(\alpha + \beta) \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

The most dangerous situation is that where α has a value such that this expression reaches a maximum. This occurs at:

$$\operatorname{tg} \alpha = \frac{3 + \sqrt{9 + 8 \operatorname{tg}^2 \beta}}{2 \operatorname{tg} \beta} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

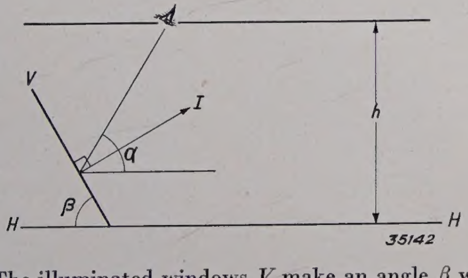

Fig. 5. The illuminated windows V make an angle β with the horizontal plane H. Their maximum luminous intensity is I. At an altitude h the window V is observed under an angle α with the horizontal plane by an observer flying in a vertical plane perpendicular to the window.

The direction α with the horizontal, in which the greatest intensity of illumination occurs on the eye, is represented in *fig. 6* as a function of the angle β which the windows make with the horizontal. With vertical windows the most dangerous direction of vision is at an angle β of nearly 55°.

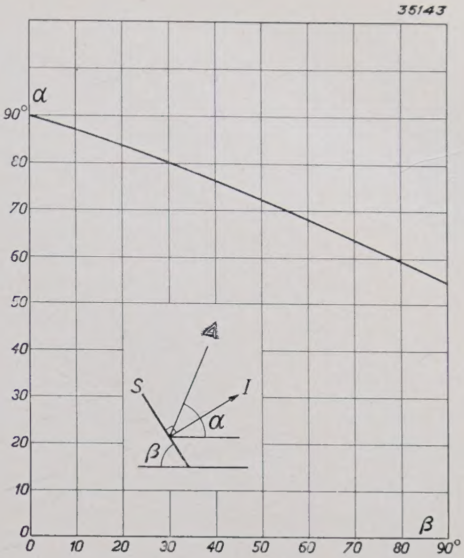

Fig. 6. The direction α with the horizontal plane, at which the greatest intensity of illumination strikes the eye, as a function of the angle β between the plane S of the window and the horizontal plane.

The factor K, by which the value for the permissible brightness to be read off in fig. 4 in the case of non-horizontal windows may still be multiplied, is according to formula (2), now given by:

$$K = \frac{1}{\sin^2 \alpha \sin(\alpha + \beta)}, \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

where for the sake of security in the most unfavourable case the value of α which follows from formula (3) must be substituted. In *fig. 7* factor K is plotted as a function of the slope β of the windows.

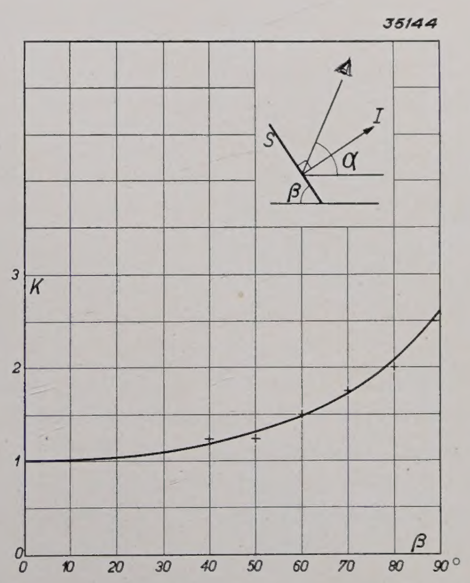

Fig. 7. For windows which make an angle β with the horizontal plane, the permissible intensity of illumination calculated for horizontal windows may be multiplied by a factor K. Several rough values of K which may be used in practice are indicated in the figure by crosses.

For several values of the slope β (fig. 5) of the windows the following values of K may be used in practice:

β	0°	30°	40°	50°	60°	70°	80°	90°
K	1	1,1	1,2	1,25	1,5	1,75	2	2,5

From now on we shall limit ourselves to a consideration of a flying altitude of 2 000 ft. If for some reason it is necessary to take other altitudes into consideration, it is only necessary to multiply the brightness found for 2 000 ft by a factor H which may be deduced from fig. 4. For the sake of simplicity this factor H is drawn in *fig. 8* as a function of the window area for several flying altitudes. It may clearly be seen that for very large surfaces it is only a question of their brightness, so that the flying altitude is of little importance.

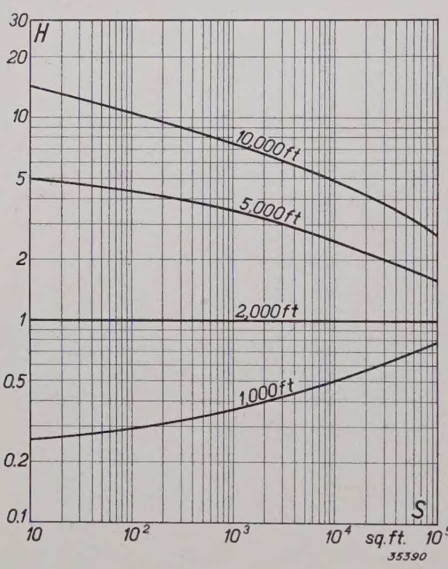

Fig. 8. For several altitudes the factor H is given as a function of window surface area S. H is the factor by which a permissible brightness calculated for an altitude of 2000 ft must be multiplied.

Level of illumination and transmissibility of the windows

From the brightness which is permissible for the light openings according to the foregoing considerations we shall now deduce the level of illumination which the interior artificial illumination may produce without being seen from the outside. With a given window area it is then a question whether or not this can be covered with a coloured coating of such a thickness that the necessary artificial illumination is sufficiently blacked out at night without the transmissibility for daylight becoming too low.

The degree to which the different spectral components of daylight are absorbed by the green layer varies very much, and therefore the transmissibility t for yellow light and that t_d for daylight for different thicknesses of paint are not simply proportional to each other. The relation between t and t_d (both expressed in %) has been measured for different kinds of paint. In *figs. 9* and *10* such paint-characteristics are reproduced for two different types of paint A and B. Curves *1* and *2* are for filtered and unfiltered sodium light respectively, and *3* is for the light of incandescent lamps in bulbs of orange Selectiva glass.

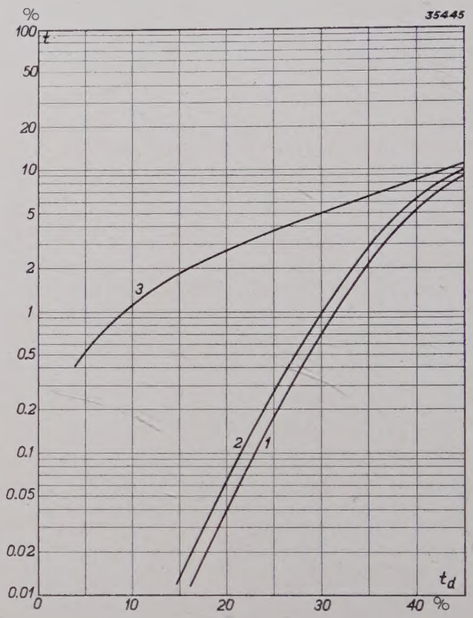

Fig. 9. For a given kind of paint A the transmissibility t for yellow light is represented as a function of the transmissibility t_d for daylight. Curves *1* and *2* are for filtered and unfiltered sodium light respectively. Curve *3* refers to the light of electric lamps fitted with orange Selectiva glass bulbs.

With a given transmissibility for daylight a combination of paint and kind of light is more suitable, the less yellow light is transmitted, *i.e.* the lower the characteristic. If for example with filtered sodium lighting (curve *1*) a daylight transmissibility of 25 per cent is required, it is found that upon use of paint A the transmissibility for the artificial light is about 0.18 per cent, while with paint B it is about 3.5 per cent. In combination with sodium light therefore paint A is much better than paint B. If artificial illumination with orange incandescent lamps is used the two kinds of paint are found to have the same transmissibility of nearly 2 per cent for the yellow light, with a daylight transmissibility of 15 per cent; for greater values of t_d paint A is better than B, but at smaller values of t_d paint B is better.

If a daylight transmissibility of about 25 per cent is required, as will usually be necessary for workshops and similar localities, sodium illumination together with paint A is the most suitable combination. If a daylight transmissibility of less than 15 per cent is adequate, as for example is usually the case in entrance halls and stairways, the combination of filtered incandescent light and paint *B* may well be used.

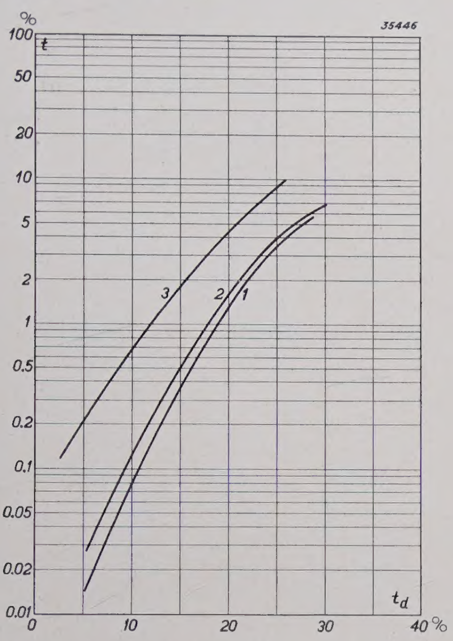

Fig. 10. Paint characteristics similar to those in fig. 9 for another paint (*B*).

In order to be able to deal with practical cases by means of our graphs it is first necessary to define more precisely what values must be taken for the different quantities occurring in them. For the area of the illuminated window surface *S*, which occurs in fig. 4, in the case of a roof or wall with many windows separated by dark strips one must take the total surface observed from the direction of the aeroplane, while as brightness the average brightness over this total surface may be taken.

In fig. 4 the brightness *B* permissible on the outside is given for every total window surface area. If one deduces from this the intensities of illumination *E* which may be permissible for the interior artificial illumination, the transmissibility *t* for the yellow light used, determined by the paint characteristic of fig. 9 or 10, is not of itself sufficient, but the proportionality factor between the intensity of illumination inside and the brightness of the light openings should also be known. Different cases may occur according as the glass of the window is diffusing or clear. With clear glass one sees through the window the illuminated background of the room whereby it is of course assumed that the light source itself is invisible. If this background has an illumination intensity of E_g, and if the reflectivity of the background is ϱ per cent, while *t* is the transmissibility expressed in per cent of the yellow artificial light following from fig. 9 or 10, the brightness observed through the window becomes:

$$B_g = 1.076 \cdot 10^{-7} \, \frac{t_g \; \varrho \; E_g}{\pi} \quad . \; . \; . \; . \quad (5)$$

With a diffusing glass pane the brightness on the outside is:

$$B_r = 1.076 \cdot 10^{-5} \, \frac{t_g \, E_r}{\pi}, \quad . \; . \; . \; . \quad (6)$$

where E_r represents the intensity of illumination on the inside of the windows. Depending on the shape of the room and the nature of the lighting system, there will be a definite relation between this E_r and the intensity of illumination E_g of the background, which may be represented by:

$$E_g = \frac{a \, E_r}{100} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

where *a* represents a constant factor expressed in per cent. The brightness for the diffusing glass may therefore be expressed as follows in terms of the intensity of illumination of the background:

$$B_r = 1.076 \cdot 10^{-7} \, \frac{t_g \, a \, E_g}{\pi} \quad . \; . \; . \; . \quad (8)$$

If we now compare formula (8) with formula (5) we see that for the case where $a < \varrho$ diffusing glass is preferable, when $a > \varrho$, however, clear glass is better.

For a normal background one may in general let ϱ equal 30 to 35 per cent, and with an ordinary indoor illumination without good shade fixtures clear glass windows will usually be preferred. The sharp reflections which may occur on the pieces of work are in this case neglected, but they are usually too small in size to be able to draw the attention of an observer from the air. In the case of frosted glass windows this difficulty does not arise, since in that case the surface of the window acts as a secondary light source. In factories in which many white objects are present (white paper in printing establishments, light coloured textiles in textile mills), one must count on a higher coefficient of reflection of 60 to 70 per cent, and in such cases diffusing glass will be preferable, especially when the light sources are so shaded that they produce no direct illumination on the windows.

Diagrams

In order to be able in a simple way to obtain an idea of the levels of illumination which may be permitted in the room in question in combination with the desired values for daylight transmissibility, diagrams may be used which give a direct relation between the permissible intensity of illumination E, the daylight transmissibility t_d and the window surface area S, while all auxiliary quantities are eliminated.

In *fig. 11* such a diagram is given for filtered sodium light in combination with paint A (*i.e.* corresponding to curve *1* in fig. 9). In this diagram therefore one may immediately read off the combination of daylight transmissibility and intensity of artificial illumination with which horizontally placed windows with a given area may be blacked out satisfactorily in this way. According to the foregoing, it is advisable in printing establishments and other industries where the average background is light in colour to allow only half the intensity of illumination which would follow from the diagram. If the windows are vertical an intensity of illumination which is 2.5 as great as what would follow from the diagram may be permitted. If the windows are diffusing only about 0.3 of the intensity which would follow from the diagram must be allowed on the inside of the windows. From this diagram one may also read off immediately the maximum window surface area which can be blacked out satisfactorily in this way, if given minimum requirements are made not only for the daylight transmissibility but also for the level of artificial illumination.

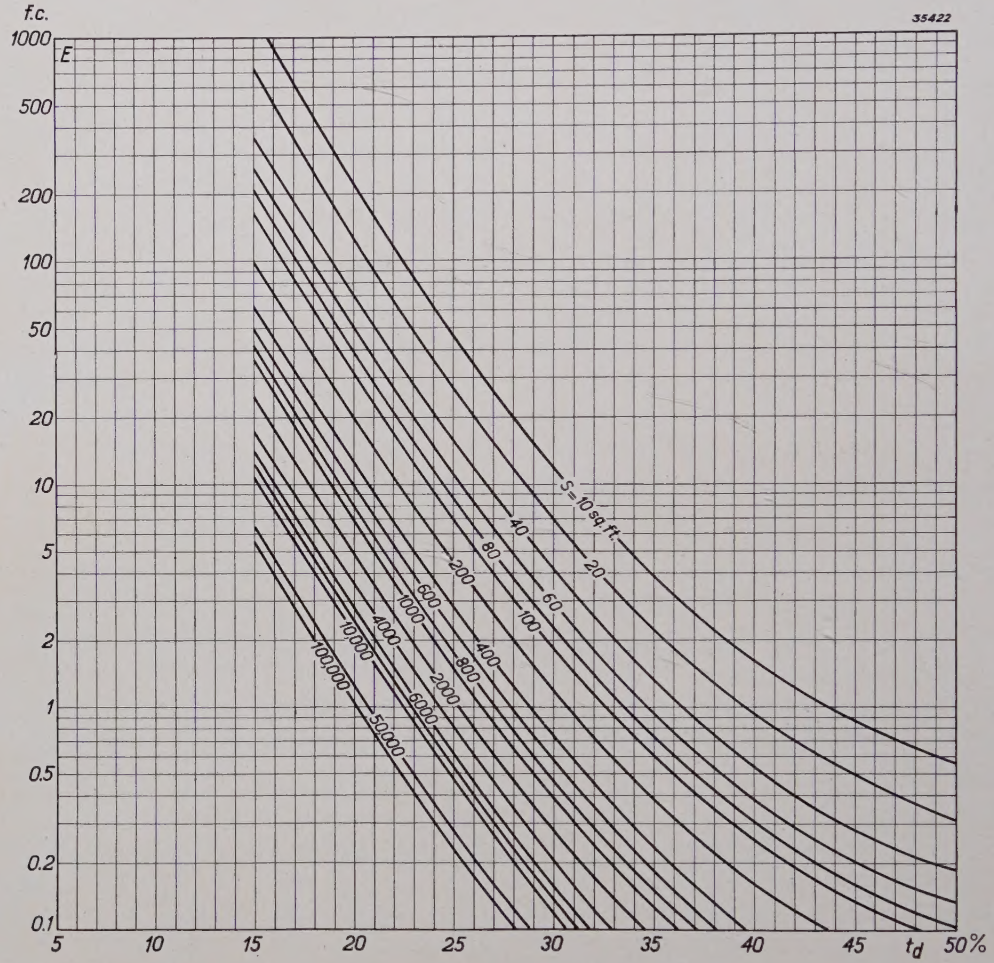

Fig. 11. By means of this graphical representation the relation is determined which exists when filtered sodium light is used in combination with paint A between the daylight transmissibility t_d, the permissible intensity of illumination E with horizontal, clear glass panes, and the area S of the window surface which must be blacked out, for a flying altitude h of 2 000 ft.

Fig. 12 refers to filtered incandescent light in combination with paint B (*i.e.* corresponding to curve *3* of fig. 10). It may be seen that good results may be obtained if the window surfaces are not too large, and if a moderate daylight transmissibility is considered satisfactory.

With diagrams such as those in figs. 11 and 12 it is possible to answer various questions. If a room with a given window surface area S must be provided with wartime illumination, it may be asked for example how much one would lose in permissible daylight transmissibility if more artificial light should be demanded. Fig. 11 immediately supplies the following answer to this question. If for example approximately a 30 per cent more intense artificial illumination were desired, this would mean a decrease of the daylight transmissibility of only one per cent from 26 per cent to 25 per cent for instance.

The manner in which this diagram may be used in practice will be illustrated in the following by means of some simple examples.

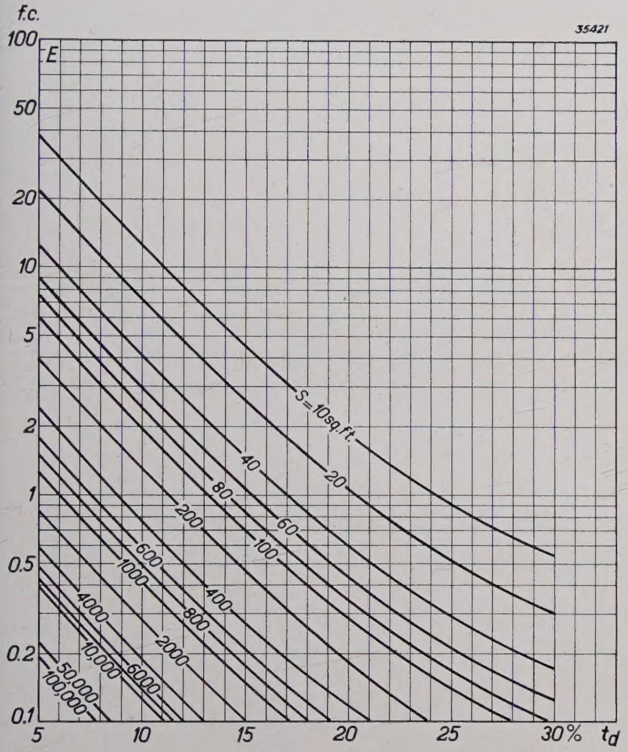

Fig. 12. Analogous graphical representation to that of fig. 11; here, however, for the light of orange Selectiva glass lamps in combination with paint *B*.

Practical examples

In a workshop with a vertical window surface area of 100 sq.ft a wartime illumination system of sodium lamps in orange Selectiva vacuum jackets is installed, while the diffusing panes are to be covered with paint *A* in such a way that they still transmit 25 per cent of the daylight. From fig. 11 the intensity of illumination may be found which the sodium lamps may produce on the inside surface of the frosted glass. For horizontal clear glass windows we find that the permissible intensity on the piece of work would be 7 ft.c. For vertical windows this may be multiplied by 2.5, while in order to obtain the intensity of illumination on the inner side of the diffusing glass windows this result must still be multiplied by 0.3. The result is the following:

$$0.3 \times 2.5 \times 7 = 5.25 \text{ ft.c.}$$

If a much higher horizontal intensity of illumination were desired, and an illumination of 20 ft.c. on the inside of the windows were unavoidable, it is equivalent to $E = \frac{20}{2.5 \times 0.3} = 27$ ft.c in fig. 11, where for a surface of 100 sq.ft. a daylight transmissibility of approximately 21 per cent is found. The question then is whether, for the case in question, this is sufficient.

As a second example we shall consider the case of a roof with a surface of 6 000 sq.ft, 40 per cent of which consists of diffusing glass, and which makes an angle of 70° with the horizontal. It is desired to retain 25 per cent of the daylight, and filtered sodium light is to be used in combination with paint *A*. In fig. 11 *E* is found to be about 0.61 ft.c. The permissible intensity of the illumination on the inside of the diffusing windows, which only occupy 0.4 of the total surface area, may be taken 2.5 as high, and must, moreover, due to the 70° slope, be multiplied by a factor 1.75, and due to being diffusing by a factor 0.3, so that the result would be about 0.8 ft.c. By screening off all direct illumination it must therefore be tried to keep the intensity of illumination on the inside of the windows below 0.8 ft.c. If this is impossible, part of the windows must be covered by blinds, and the others fitted out by the filter method. If in this case it were only necessary to guarantee invisibility for a flying altitude of at least 5 000 ft. then according to fig. 8 the intensity of illumination could be 2.7 times higher, *i.e.* 2.16 ft.c.

THE HUM DUE TO THE MAGNETIC FIELD OF THE FILAMENTS IN TRANSMITTING VALVES

by K. POSTHUMUS.

621.396.822 : 621.396.615.1

When the filament of a directly heated electron tube is fed with alternating current, a periodic change in the rhythm of the mains frequency occurs in the properties of the tube. In particular the anode current will exhibit a periodic fluctuation which gives rise to hum. In the case of transmitting valves the most important cause of hum is the periodically changing magnetic field of the filaments. The influence of the magnetic field is discussed theoretically in this article. The results are tested by comparing them with the results of measurements carried out on the transmitting valve, type TS 20/30. In conclusion a theoretical and experimental study is given of attempts to decrease hum by dividing the filament system into a number of parts which are fed with alternating currents of different phase.

When the filaments of directly heated electron tubes are heated with alternating current in order to simplify the connections, the properties of the tube will in general exhibit a periodic fluctuation in the rhythm of the A.C. voltage. This is understandable, since different quantities which influence the operation of the tube vary periodically. The following properties are chief among these:

a) the temperature of the filament,

b) the voltage along the filament,

c) the magnetic field of the filament.

With small electron tubes, such as ordinary radio amplifier valves, the filaments are so thin that upon direct heating with alternating current their temperature fluctuations would assume values far beyond those permissible. Indirectly heated cathodes are therefore used, which have a much larger heat capacity. Moreover in this case the filament is shielded by a nickel tube by which the fluctuations mentioned under b) are also avoided. By winding the filament bifilarly the fluctuations mentioned under c) can be made practically harmless.

In the case of large transmitting valves, for instance water-cooled transmitting valves for high power, the filaments are in general so thick that their temperature scarcely fluctuates at all when they are heated with alternating current. The variations in the voltage along the filament and those of the magnetic field of the filament, however, may cause fairly considerable fluctuation of the anode current, so that the high-frequency anode alternating current experiences a modulation which is later observed as hum in the reception. The influence of the magnetic field of the filament is usually the greater of the two causes of hum, and this will be discussed in some detail in this article.

If we wish to study mathematically the influence of the magnetic field on the motion of the electrons, we must make several simplifying assumptions about the geometric configuration of the valve. In the case of water-cooled transmitting valves a number of filaments are arranged to form a cylindrical shell, while around this at a certain distance is a second cylinder (the control grid) which has a different potential from that of the filaments.

We shall consider both cylindrical surfaces as equipotential surfaces, and assume that the inner cylinder is uniformly covered with emitting wires. The problem is then reduced to that of two concentric cylinders between which electrons move under the influence of a radial electric field and a magnetic field perpendicular to the electric field and to the axis of the cylinder. We shall simplify the problem still further by taking plane electrodes instead of the cylindrical electrodes (see *fig. 1*).

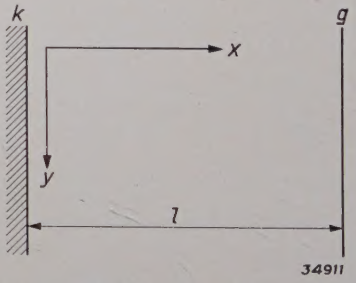

Fig. 1. Simplified model of a transmitting valve for the calculation of the influence of the magnetic field due to the heating current, *k* plane cathode surface, g plane grid surface at a distance *l* from the cathode. The magnetic field is perpendicular to the plane of the drawing.

In the following the anode current of the model, so obtained and differing so much from the actual transmitting valves, will be calculated as a function of the magnetic field. We shall then ascertain how conclusions can be drawn from the results about the behaviour of valves actually constructed, and to what degree the results are confirmed experimentally.

Statement of the problem

We imagine the cathode of fig. 1 to be extended infinitely in all directions of the y-z plane, while the electrons move in the x direction with the initial velocity zero. The magnetic field H varies in the z direction and is assumed to be dependent only on x.

The electrons which leave the cathode are accelerated in the x direction by the fall in electric potential V. The value of the field is determined not only by the potentials of the various electrodes, but also by the space charge of the electrons situated between cathode and control grid. This space charge, which is proportional to the current, exerts a repelling action on the following electrons, which are just about to leave the cathode, in other words, it lowers the field strength at the surface of the filament. At a certain value of the current the electric field at the surface of the filament vanishes, and this value is the current which actually prevails. If a still larger number of electrons per second should be emitted than that which corresponds to this current, the electric field would become negative, and would drive back just enough of the electrons to bring the current back to the limiting value mentioned.

Due to the presence of the magnetic field the electrons will describe curved paths, and will therefore be unable to leave the filament as quickly as would otherwise be the case. The space charge is thus increased, and will therefore cause the electric field at the cathode surface to vanish at a smaller limiting value of the anode current.

This decrease in the anode current due to the magnetic field forms the object of our calculations.

The equations of motion of an electron

If $-e$ is the charge and m the mass of an electron, the motion of the electron satisfies the following equations:

$$e\,\frac{\mathrm{d}V}{\mathrm{d}x} - H(x)\,e\,\frac{\mathrm{d}y}{\mathrm{d}t} = m\,\frac{\mathrm{d}^2x}{\mathrm{d}t^2} \quad . \; . \; . \quad (1)$$

$$H(x)\,e\,\frac{\mathrm{d}x}{\mathrm{d}t} = m\,\frac{\mathrm{d}^2y}{\mathrm{d}t^2} \quad . \; . \; . \; . \; . \quad (2)$$

In a previous article in this periodical ¹), in explaining the operation of the magnetron, the solution of these equations was dicussed for the case in which the electric field, $E = -\mathrm{d}V/\mathrm{d}x$, is constant throughout the whole of space. In our case, in which the potential is influenced by the space charge, the method of solution there given is however unsuitable and we must find another.

If we multiply (1) by $\mathrm{d}x/\mathrm{d}t$, and (2) by $\mathrm{d}y/\mathrm{d}t$ we can eliminate $H(x)$ by adding the two equations. One then obtains the following:

$$e\,\frac{\mathrm{d}V}{\mathrm{d}t} = m\left(\frac{\mathrm{d}x}{\mathrm{d}t}\,\frac{\mathrm{d}^2x}{\mathrm{d}t^2} + \frac{\mathrm{d}y}{\mathrm{d}t}\,\frac{\mathrm{d}^2y}{\mathrm{d}t^2}\right),$$

from which it follows that:

$$\tfrac{1}{2}\,m\left[\left(\frac{\mathrm{d}x}{\mathrm{d}t}\right)^2 + \left(\frac{\mathrm{d}y}{\mathrm{d}t}\right)^2\right] = e\,V(x) \quad . \; . \; . \quad (3)$$

This already takes into account the condition that at the surface of the filament ($V = 0$) the x component as well as the y component of the velocity disappears. Equation (3) is nothing else than the law of conservation of energy, and expresses the fact that the magnetic field does no work.

In order to carry the integration farther we must know $V(x)$ as a function of the coordinate. $V(x)$ is equal to zero at the surface of the cathode ($x = 0$), and has a certain effective value V_e in the grid plane ($x = l$). The variation in the space between grid and cathode is determined by the differential equation.

$$\frac{\mathrm{d}^2V}{\mathrm{d}x^2} = 4\,\pi\,\varrho, \quad . \; . \; . \; . \; . \quad (4)$$

where ϱ is the density of the space charge. Between the space charge ϱ, the local velocity $\mathrm{d}x/\mathrm{d}t$ of the electrons and the current i the following relation exists:

$$i = \varrho(x)\,\frac{\mathrm{d}x}{\mathrm{d}t} \quad . \; . \; . \; . \; . \; . \quad (5)$$

The current i indicated in equation (5) is the so-called "convection current" which is caused by the motion of charged particles. Since the magnetic field changes relatively slowly (compared with the transit time of the electrons) we may consider the situation as practically stationary. The convection current then corresponds to the total current and is therefore not a function of x.

The calculation of the anode current

From equations (4) and (5) it follows that:

$$\frac{\mathrm{d}^2V}{\mathrm{d}x^2} = \frac{4\,\pi\,i}{\dfrac{\mathrm{d}x}{\mathrm{d}t}} \quad . \; . \; . \; . \; . \; . \; . \quad (6)$$

This equation may be integrated if $\mathrm{d}x/\mathrm{d}t$ is known as a function of x. We first calculate from equation (2):

$$m\,\frac{\mathrm{d}y}{\mathrm{d}t} = e\int_0^x H\,(x)\,dx,$$

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¹) Philips techn. Rev. 4, 189, 1939.

having made use of the fact that for $x = 0$ $\mathrm{d}y/\mathrm{d}t$ disappears. The integral on the right we shall call $F(x)$ in the following. With the help of equation (3) we now find that:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sqrt{2\frac{e}{m}V - \left[\frac{e}{m}F(x)\right]^2}$$

and thus by substituting in (6):

$$\frac{\mathrm{d}^2V}{\mathrm{d}x^2} = \frac{4\pi i}{\sqrt{2\frac{e}{m}V - \left[\frac{e}{m}F(x)\right]^2}} \quad . \; . \; . \quad (7)$$

In order to solve this differential equation we must make a special choice of the function F, that is, of the magnetic field H. In practice the variation of the magnetic field may be very different according as the currents through the different filaments are all in the same direction, or alternately in opposite directions, or follow some other rule. We shall consider a number of different cases, and investigate whether it is possible to draw a general conclusion from them.

1. *No magnetic field*

If the magnetic field may be neglected, and thus if $F(x) = 0$, equation (7) passes over into the well known differential equation of Langmuir which may be solved by setting

$$V = k \cdot x^{4/3} \quad . \; . \; . \; . \; . \; . \; . \quad (8)$$

This can easily be tested by differentiating equation (8) twice, and substituting $\mathrm{d}^2V/\mathrm{d}x^2$ and V in differential equation (7). One then finds that this equation is satisfied if the coefficient k has a definite value, namely:

$$k = \left(\frac{9\pi i}{\sqrt{2e/m}}\right)^{2/3} \quad . \; . \; . \; . \; . \; . \; . \quad (9)$$

The solution of the differential equation thus found satisfies the above-mentioned condition that the field-strength $-\mathrm{d}V/\mathrm{d}x$ equals zero at the surface of the cathode ($x = 0$). The current corresponding to this is therefore the desired anode current. By filling in the above value of k in equation (8) one finds:

$$18\pi i\frac{e}{m} = \frac{\left(\frac{2e}{m}V\right)^{3/2}}{x^2}.$$

V is here the potential at the point x which may be chosen arbitrarily. When x is taken equal to l then $V = V_e$, and one obtains:

$$18\pi i\frac{e}{m} = \frac{\left(\frac{2e}{m}V_e\right)^{3/2}}{l^2} \quad . \; . \; . \; . \quad (10)$$

From this relation the current i is known, if the distance l and the potential difference V_e in the plane of the grid are given.

We shall now examine how this current changes due to the presence of the magnetic field of the filament.

2. *Weak magnetic field*

The differential equation may be solved for a fairly general form of the magnetic field, which must however satisfy the condition that H depends only on x, when the restriction is introduced that the magnetic field is weak, and thus that F is always small. In that case we may substitute for the square root occurring in differential equation (7) a development in a series to obtain a good approximation. The influence of the magnetic field on the variation of the potential may then be represented by a small correction in the variation of potential between the electrodes calculated above for $H = 0$. Instead of equation (8) therefore we write:

$$V = \left(\frac{9\pi i}{\sqrt{\frac{2e}{m}}}\right)^{2/3} x^{4/3} + w(x) \quad . \; . \; . \quad (11)$$

and when the correction term w is known, we may deduce from this equation the manner in which the current i varies with the magnetic field which determines the term w. In order to determine w equation (11) must be differentiated twice, and the quantity $\mathrm{d}^2V/\mathrm{d}x^2$ so obtained, as well as V must be substituted in the original differential equation (7). When in the resulting expression, the square root is expanded into a series, of which only the first two terms are considered, a simple linear differential equation of the second order is obtained for w, namely:

$$\frac{\mathrm{d}^2w}{\mathrm{d}x^2} + \frac{2}{9}\frac{w}{x^2} = \frac{1}{9}\frac{e}{m}\left(\frac{F(x)}{x}\right)^2.$$

This equation is easily solved. The "homogeneous solution" may for example first be determined, which occurs when the right-hand member is equal to zero, and then the right-hand member may be considered by the so-called method of "variation of the constants". The result of this calculation, which we shall not give in detail [2]), is:

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[2]) For the intermediate calculations see Philips Transm. News. No. 1, 1940, where the calculations are published in a considerably more detailed form. In addition to the case of plane electrodes the case of cylindrical electrodes is also dealt with.

$$w = \frac{x^{2/3}}{3}\int_0^x \xi^{-5/3}\frac{e}{m}\left[F(\xi)\right]^2 \mathrm{d}\,\xi - \frac{x^{1/3}}{3}\int_0^x \xi^{-4/3}\frac{e}{m}\left[F(\xi)\right]^2 \mathrm{d}\xi \qquad (12)$$

When the function $w(x)$ so obtained is substituted in equation (11), and the resulting equation is again solved for the current, we find that the current is altered by the presence of the magnetic field.

In order to obtain comprehensible results we choose for the variation of the magnetic field the special form:

$$H(x) = H(x/l)^n,$$

where n must be a negative power since the magnetic field becomes weaker with increasing value of x. Without indication of place H indicates here and in the following the field strength in the grid-place ($H(l)$).

The function $F(\xi)$ which appears in (12) now becomes:

$$F(\xi) = \int_0^\xi H(x)dx = \frac{H}{n+1}\,\xi^{n+1}.$$

For this form of $F(\xi)$ the integration in equation (12) can immediately be performed. The expression for w so obtained is substituted in equation (12). When the resulting equation is solved for the anode current we obtain:

$$\left.\begin{aligned} &18\,\pi\, i\,\frac{e}{m} = \left(\frac{2e}{m}V_e\right)^{3/2}\left[\frac{1}{l^2} - \frac{1}{6}\,\frac{e\,H^2}{m\,V_e\,N}\right], \\ &\text{where} \\ &N = \left(n+1\right)^2\left(2\,n+\frac{5}{3}\right)\left(2\,n+\frac{4}{3}\right). \end{aligned}\right\} \quad . \qquad (13)$$

This is the final result. It may be seen that the magnetic field acts to lower the anode current, and this lowering is proportional to the square of the magnetic field and inversely proportional to the effective grid voltage. This is of course only a first approximation, and it may be expected that higher powers of H will appear with strong magnetic fields.

Discussion of the results

Further consideration of the calculation shows that the result given in equation (13) is only reliable for values of n which are not more negative than $-^1/_2$. For a number of values of n between zero and $-^1/_2$ the variation of the anode current as a function of the magnetic field in the plane of the grid as calculated according to equation (13) is shown in *fig. 2* (dotted lines). The parameters of the six curves give the exponent n in the above formula for the field strength.

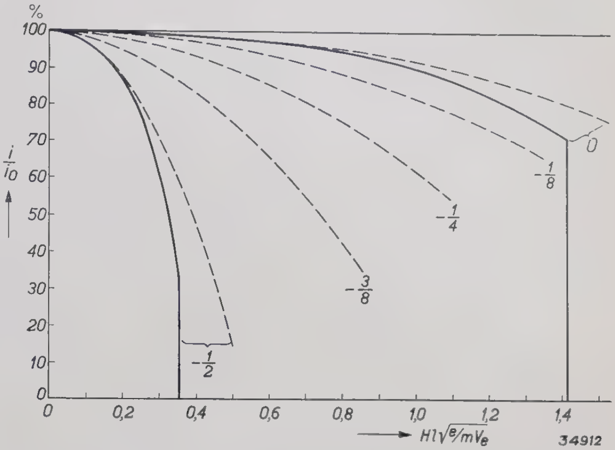

Fig. 2. Variation of the anode current in per cent of the maximum value as a function of the magnetic field strength in the grid plane *l* (expressed by the dimensionless quantity $H/\sqrt{e/mV_e}$). The parameters indicate the value of the exponent n in the expression for the variation of the magnetic field: $H(x) = H/(x/l^n)$. Continuous curves: $n = 0$ and $n = -^1/_2$. Broken line curves: variation calculated in a first approximation (equation (13)) for $n = 0, -^1/_8, -^1/_4, -^3/_8, -^1/_2$.

When the variations of the anode current as a function of the filament current (*i.e.* as a function of the magnetic field) are examined with the help of an oscillograph, it is found that the parabolic curves given in fig. 2 correspond very well with actuality if the decrease in the anode current is not more than about 25 per cent. The further decrease in the anode current with increasing filament current, and thus with increasing field, takes place more rapidly than is to be expected from the calculation.

In order to find out to what extent this discrepancy can be explained theoretically an attempt was also made to find exact solutions for equation (7) in addition to the above approximation. This is possible for $n = 0$, *i.e.* with a homogeneous magnetic field and for $n = -^1/_2$, *i.e.* for $H(x) = H/\sqrt{x/l}$. The calculation, which we shall not discuss here, leads to the continuous curves of fig. 2. If these are compared with the broken line curves corresponding to the same value of n, a good agreement is actually found at low fields H, while the current at high fields decreases more rapidly and suddenly disappears entirely at a definite maximum field strength.

The exact calculated curves for $n = 0$ and $n = -^1/_2$ are very similar. This similarity becomes more pronounced when instead of the current, the percentage decrease of current is used as ordinate, and as abscissa, instead of the field strength, the ratio H/H_m, when H_m is the critical field which causes the anode current to disappear suddenly. In *fig. 3* the curves for $n = 0$ and $n = -\frac{1}{2}$ are shown for these new coordinates. It may be seen that the variation is practically proportional for all field strengths, and that the curve for $n = -\frac{1}{2}$ is a factor 2.4 higher than the curve for $n = 0$.

The good agreement between the two curves, which refer to two very different field distributions, makes it probable that the variation of the decrease in current as a function of H/H_m indicated by this curve may be assumed to hold for every field distribution except for a factor. This circumstance makes it possible to apply the results found on the very much simplified model to actually constructed transmitting valves with some chance of success, as will presently be done in drawing our practical conclusions.

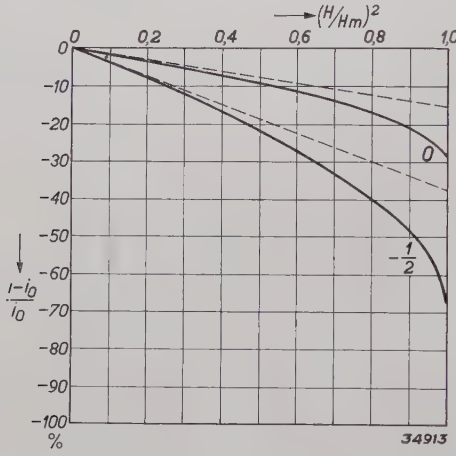

Fig. 3. Percentage decrease of the anode current as a function of H/H_m for $n = 0$ and $n = -\frac{1}{2}$. H_m is the value of the field at which the anode current suddenly disappears. The curves have practically the same shape, with the difference that the lowering at $n = -\frac{1}{2}$ is a factor 2·4 greater than that at $n = 0$.

The "hum" of transmitting valves

In *fig. 4* the accurately calculated variation (continuous line) of the anode current as a function of H/H_m is again plotted for a field distribution:

$$H(x) = \frac{H}{\sqrt{x/l}}\,.$$

The percentage decrease of the anode current as a function of H/H_m can be very well approximated by the following series:

$$\frac{i_0 - i}{i_0} = 0{,}375\left(\frac{H}{H_m}\right)^2 + 0{,}12\left(\frac{H}{H_m}\right)^4 + 0{,}18\left(\frac{H}{H_m}\right)^{26}$$

which gives the points in the figure. If we assume that this formula is valid, except for a factor, for any given distribution of the magnetic field between the plane of the cathode and that of the grid, we find the following general formula for the anode current as a function of the effective grid voltage and the magnetic field:

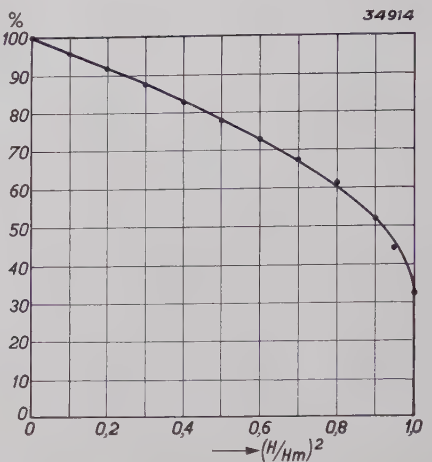

Fig. 4. Variation of the anode current in per cent of the maximum value as a function of H/H_m for a field distribution $H(x) = H/\sqrt{x}$. The curve may be represented by:
$i = i_0\ (1 - 0.375\ (H/H_m)^2 - 0.12\ (H/H_m)^4 - 0.18\ (H/H_m)^{26}$.

$$\left.\begin{aligned} &\frac{e}{m}\,\pi\, i = \frac{1}{18\, l^2}\left(2\,\frac{e}{m}\,V_e\right)^{3/2}\left[1 - p\,G\left(\frac{H}{H_m}\right)\right], \\ &\text{where} \\ &G\left(\frac{H}{H_m}\right) = 0{,}375\left(\frac{H}{H_m}\right)^2 + 0{,}12\left(\frac{H}{H_m}\right)^4 + 0{,}18\left(\frac{H}{H_m}\right)^{26}. \end{aligned}\right\} \quad (14)$$

p is here a factor which depends upon the distribution of the magnetic field. For the above-mentioned field $H(x) = H/\sqrt{x/l}$, $p = 1$, for a homogeneous field $p = 1/2.4 \sim 0.4$.

If p is known, it is possible with the help of equation (14) to calculate how the anode current varies when a transmitting valve is fed with sinusoidal alternating current. Since the quantity H in equation (14) is proportional to the filament current, the anode current i will be composed of a D.C. component and a ripple whose fundamental frequency is equal to twice the mains frequency. In addition the ripple also contains higher harmonics which come from the terms with $(H/H_m)^4$ and $(H/H_m)^{26}$.

The calculation is not difficult but rather complicated [3]) and leads to formulae which are not very clear. We shall therefore confine ourselves to a general discussion of the results.

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[3]) See the article cited in note [2]).

Hum as a function of the effective anode current

The variation of the hum as a function of the effective anode current can be comprehended qualitatively on the basis of equation (13), in which the anode current is represented in first approximation as a function of the effective potential V_e and the magnetic field H in the plane of the grid. This equation has the following character:

$$i = A\,V_e^{3/2} - B\,V^{1/2}\,H^2,$$

where A and B are constants which are determined by the construction of the transmitting valve.

With a sinusoidally alternating heating current, $H(l)$ is also sinusoidal. If ν is the mains frequency and H_0 the amplitude of the sinusoidal vibration, then:

$$H^2 = H_0^2 \sin^2 2\,\pi\,\nu\,t = H_0^2\,(1/_2 - 1/_2 \cos 4\,\pi\,\nu\,t)$$

and therefore

$$i = \underbrace{A\,V_e^{3/2} - 1/_2\,B\,H^2\,V_e^{1/2}}_{i_g} - \underbrace{1/_2\,B\,H^2\,V_e^{1/2} \cos 4\,\pi\,\nu\,t}_{i_w} \quad \dots \quad (15)$$

It may be seen that the anode current is composed of a D.C. component i_g which in first approximation is proportional to the three halves power of the effective grid voltage, and an A.C. component which increases with the square root of the grid voltage and is thus proportional to the cube root of the anode direct current.

The effective value of this A.C. component is called the hum current. We are however usually more interested in the so-called hum modulation, which is defined as the ratio between the hum current and the anode direct current. It follows from equation (15) that the hum modulation — at least for sufficiently small values of the field H_0 — is inversely proportional to the effective grid voltage or to the two thirds power of the anode direct current.

In *fig.* 5 the hum current and hum percentage calculated by means of equation (14) are plotted as functions of the effective grid voltage. Three values of the parameter p have been chosen, namely 0.5, 1 and 1.5. $p = 0.5$ corresponds to a magnetic field which decreases only slightly with increasing value of x ($p = 0.4$ for the homogeneous field); $p = 1$ corresponds to the case of a field distribution according to $H/\sqrt{x/l}$, while $p = 1.5$ relates to the case where the field decreases even more rapidly with increasing distance from the cathode. In agreement with the above qualitative discussion the hum current is found to be proportional to $i_g^{1/3}$, while the hum percentage is proportional to $i_g^{-2/3}$. Only at very low effective grid voltages, at which the hum percentages become significantly large, do deviations plainly occur.

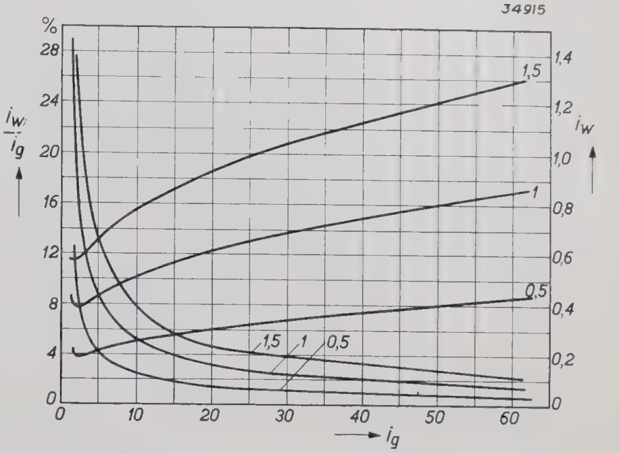

Fig. 5. Effective value of the hum current i_w (arbitrary units) and the hum percentage i_w/i_g, as functions of the effective anode direct current (arbitrary units). The three curves are calculated according to equation (14) with the parameters $p = 0.5$, $p = 1$ and $p = 1.5$.

The results were tested by measurements of the hum of a transmitting valve (type TA 20/23) as a function of the effective grid potential. The points measured are indicated in fig. 6, while the smooth curves in this figure were calculated theoretically with $p = 1.5$. It may be seen that good agreement is obtained. From the large value of p it follows that the magnetic field decreases more rapidly than $H/\sqrt{x/l}$ with increasing distance from the cathode.

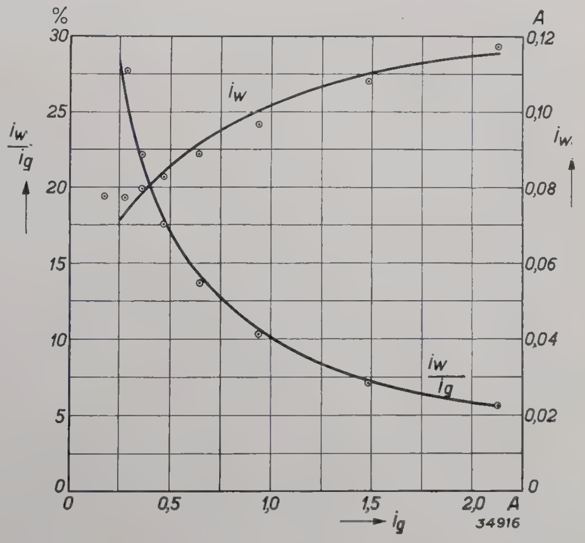

Fig. 6. Hum current i_w and hum percentage i_w/i_g of the transmitting valve type TA 20/30 as functions of the anode current. Circles: measured points, continuous lines: curves calculated with $p = 1.5$.

It is clear that with a valve of the type mentioned hum percentages of from 10 to 30 percent occur, so that one might conclude that the application of A.C. supply with such a valve would be entirely impossible. Upon closer consideration of the mechanism for the generation of the oscillations, however, it is found that the hum percentage of the signal transmitted is at least a factor 10 smaller than that of the valve itself.

Method of combatting hum

An obvious method of decreasing the hum is by dividing the filament system of the valve into a member of equal parts, and connecting these parts to the alternating current at different phases. If the hum current were proportional to $(H/H_m)^2$, as is the case in the first approximation, the use of two phases differing by 90° would already be enough to neutralize the hum entirely. The square of the field contains, in addition to a constant term, only the second harmonic of the mains frequency. This has a phase difference in the two halves of the filament system of $2 \times 90^\circ = 180^\circ$, so that the two contributions to the anode current from the two halves of the cathode fluctuate in opposite phases, and the total anode current remains constant.

Due to the term $(H/H_m)^4$, however, a fourth harmonic, in addition to the second harmonic of the mains frequency, also occurs, which cannot be compensated by a division of the system into two halves. Practically, however, this term is of little significance; with a ratio H/H_m of 0.7 it would have only 1/30 of the amplitude of the fundamental frequency, and with smaller amplitudes its influence is much smaller. The last term $(H/H_m)^{26}$ may be entirely disregarded.

If the filament system is divided into three equal parts fed with the three phases of a pure multiphase current, the fourth harmonic will also be eliminated. The mutual difference in phase is 120°, and $4 \times 120^\circ$ coincides again with 120°. If the term $(H/H_m)^{26}$ is left out of consideration, therefore, the hum should disappear entirely.

Comparative tests were carried out on several valves of different power between the hum on connection with one phase and that on connection with two phases differing by 90°. The connection with three phases led to structural complications in connection with the condition that transmitting valves must also be able to be fed with direct current. The improvement achieved amounted in one case approximately to a factor $4^1/_2$, in another case to a factor of about 10. The theoretical improvement which, even in the case of the highest hum modulation investigated and where the term $(H/H_m)^4$ is still significant, should have amounted to a factor of more than 30, was thus far from being realized. This may probably be ascribed to the fact that the two halves of the filament which are connected to the different phases are never exactly equal, due to slight asymmetry in the construction, so that the fundamental frequency of the hum is never entirely compensated.

Fig. 7 shows a transmitting valve whose filament can be fed with alternating current of two phases. The two halves of the filament system are provided with separate connecting wires, so that the filament has four connections instead of two.

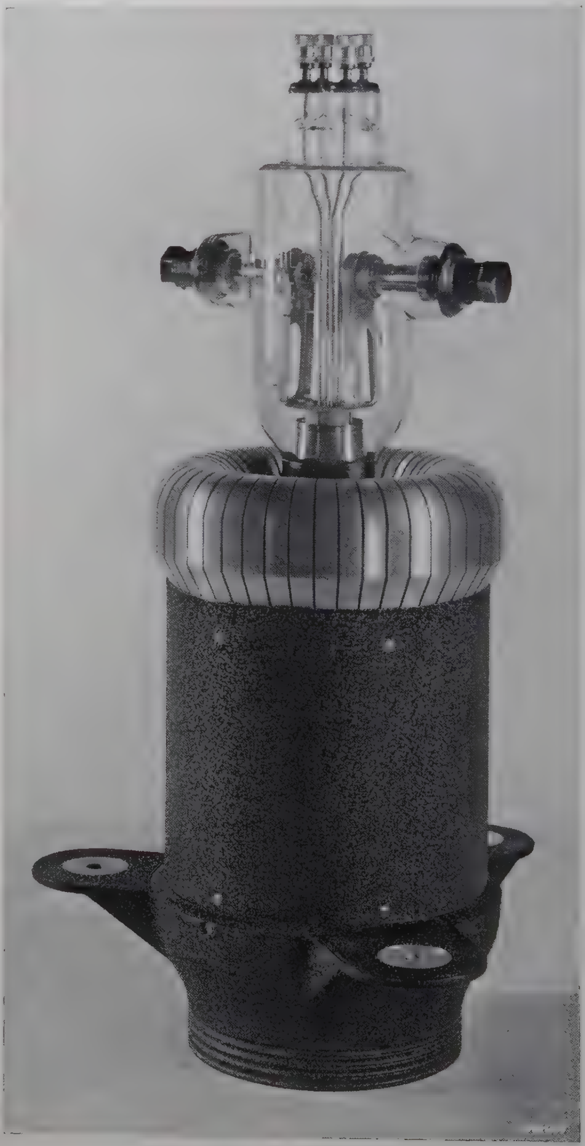

Fig. 7. The transmitting triode type TAL 12/10 (12 kV, 10 kW) with four connecting wires for the filament which is heated with two-phase alternating current.

The valve is a triode which is cooled with compressed air [4]), and which has a power output of 10 kW at an anode voltage of 12 kV. In addition to this two other valves have been developed with two-phase filament systems; a water-cooled triode of 12 kV, 35 kW, and a watercooled pentode of 12 kV, 20 kW.

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[4]) On transmitting valves cooled with compressed air, see Philips techn. Rev. 4, 121, 1939.

STEREOPHONIC SOUND REPRODUCTION

by K. de BOER.

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In the ordinary electrical methods of sound reproduction, the perception of direction, which is an essential part of hearing, is lost. After a short survey of the principles of localized hearing the article describes the way in which sound reproduction with retention of the perception of direction, *i.e.* stereophonic reproduction, could be realized. An arrangement which might be used in cinemas is described. It is found to be practically impossible to reproduce the differences of both intensity and time, which are responsible for directional hearing, in the correct relation from the point of view of the hearer. In order to examine the deviations from the "correct" perception of direction which may occur, an investigation has been carried out on the cooperation of time and intensity differences. The results of this investigation are given briefly. In conclusion several practical factors are mentioned in connection with stereophonic reproduction.

An essential part of our perception of sound is a space impression as to the origin of the sound. When for some reason or other the perception of direction from which a sound comes is lacking we often experience an uncomfortable feeling, a feeling of disquietude. This is quite understandable when the hearing function is considered from the teleological point of view. The original function of our sense of hearing may be considered to be that of warning us against danger. This is in agreement with the fact that although we possess eyelids we have no "earlids", in other words there is no provision for temporary suspension of hearing at will, since danger may always be lurking. A warning of danger may be given by the rustling of bushes in the woods, or by the hooting of a claxon at a street crossing, it can however only be useful to the hearer when his ear also perceives from what direction the danger comes, and to some extent also how close it is.

Sounds which have nothing to do with any danger are also customarily associated with a position in space. If there are several sources of sound, such as the different speakers in a play, we distinguish between them by means of directional hearing, and we take it for granted that the acoustic and the visual perceptions agree. In the same way our impressions in listening to a concert performed by a large orchestra are very much influenced by the fact that we hear the sound from the separate instruments coming from different directions, and can identify them not only by their timbre but also by the direction from which the sound comes. This faculty of being able to identify a particular sound when it is accompanied by a large number of other sounds is itself a very important result of directional hearing. We are able to concentrate our attention on the sound from a certain direction, and in this way to put into the background of our consciousness sounds from other directions which are disturbing or undesired at the moment [1]).

All these phenomena in our sence of hearing are nullified in the ordinary electro-acoustic methods of sound amplification and transmission now in use. When we listen at home to a radio broadcast of a concert we hear all the instruments from one direction only — the direction of the loud speaker. The plastic element of the orchestral music is lost. In listening to a radio play the hearer must depend mainly on differences in timbre (and possibly in intensity) in order to distinguish among the different voices. If several persons speak at the same time, or if there are extraneous sounds, it may become very fatiguing for the listener to concentrate his attention on one of the voices without the support of differences in direction. This fact must be taken into account by the director of the play. In sound reproduction in the cinema the lack of a directional effect may also be felt. One sees a player move across the screen for example, his voice however continues to be heard from the same direction, namely that of the loud speaker set up behind the screen. Bearing in mind that in the development of the film industry there is a continual striving toward a greater degree of "naturalness", it is clear why attemps are made to make the illusion more perfect by making it possible in reproduction to distinguish by ear the different positions of the source of sound in the original recording. In this article we shall discuss the possibility of such a stereophonic reproduction. For this purpose we shall first examine the principles of localized hearing.

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[1]) This has already been pointed out in the article: Improving defective hearing, Philips techn. Rev. 4, 316, 1939.

Principles of localized hearing

For localizing a source of sound with respect to an observer three coordinates are needed: the distance, the direction in the horizontal plane (azimuth) and the angle to this plane (height). There is little to say on the latter point: we have practically no direct perception of this factor. The impression that a sound comes from above is gained mainly by tilting the head, and thus this perception is reduced to that of a direction in the "horizontal" plane.

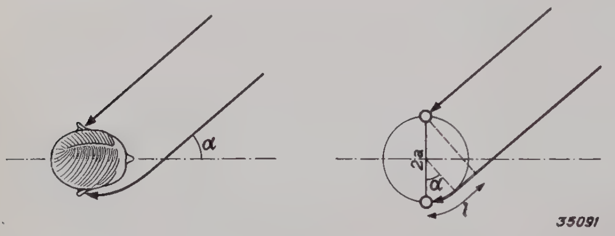

Fig. 1. Sound coming from a direction which makes an angle α with the vertical bisecting plane of the head reaches the two ears with a time difference of $t = l/c$ (c is velocity of sound). The wave which bends around the head is also weakened.

The perception of distance has not yet been entirely explained theoretically in every case [2]. In enclosed spaces it is explained by a variation in the relation between the direct sound (which reached the observer without reflection) and the echo or reverberation. When the distance of the source of sound changes the intensity of the direct sound varies, while that of the reverberation remains approximately constant. This distinguishing feature for distance is not impaired in ordinary electro-acoustic transmission, and thus provides the director of a studio program with the possibility of retaining a certain plastic effect in the reproduction.

By far the most important feature in localized hearing is the perception of direction in the horizontal plane. This depends upon the collaboration of both ears. (*Fig. 1*). If the source of sound is situated in the perpendicular plane bisecting the line joining the two ears, the latter receive exactly the same impressions. When however the sound comes from a direction α, it first reaches one ear, and only after a certain length of time the other, while moreover due to bending around the head of the observer it is somewhat weakened. Our centre of hearing is extraordinarily sensitive to these differences in time and intensity, which, led by experience, it interprets as angular deviations from the bisecting plane.

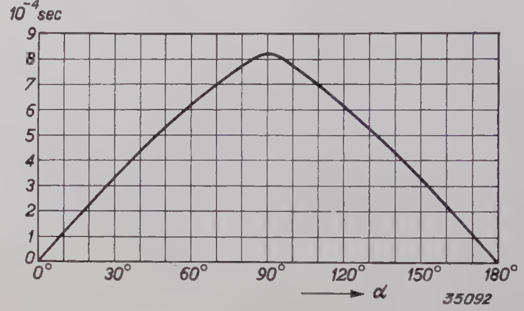

Fig. 2. Time difference t as a function of the angle α.

As to the differences in time, they can easily be calculated from the difference in distance covered l (see fig. 1) and the velocity of sound. If for the sake of simplicity the head is considered to be a sphere with the radius a, then $l = a\,(\alpha + \sin \alpha)$. It has been found experimentally that an angular deviation of only 3° from the bisecting plane can already be observed, which with a distance between the ears of about 20 cm corresponds to a difference in time of 3×10^{-5} sec. In *fig. 2* the time difference is plotted as a function of the angle α [3].

The differences in intensity at the two ears due to the bending are not so easy to calculate. They have been determined experimentally by Sivian and White [4], whose results are given in *fig. 3* for several different frequencies. The fact that the differences in intensity must also depend upon the frequency of the sound is obvious: the sound waves are only affected by an obstacle when the dimensions of the latter are of the same order of magnitude as the wave length of the sound. If the wave length is much greater than the diameter of the head, the latter does not "cast a shadow".

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[2] See in this connection: C. v. Békésy, Akust. Z. **3**, 21, 1938.

[3] The following is an interesting test of the sensitivity of the sense of hearing to time differences. The two ends of a piece of rubber tubing (gas tubing for example) are held to the ears. The tube is then tapped at any spot. The result is a clear impression of direction which depends upon the spot which was tapped. The spot which must be tapped in order to obtain the impression "straight ahead" can be determined accurately to within a few mm. See J. L. v. Soest and P. J. Groot, Physica, **9**, 111, 1939.

[4] L. J. Sivian and I. D. White, J. Acoust. Soc. Amer. **4**, 288, 1933. The curves here used are borrowed from J. C. Steinberg and W. B. Snow, Elect. Eng. **53**, 12, 1934.

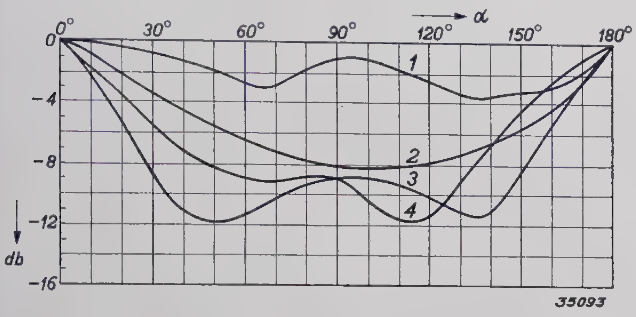

Fig. 3. Intensity difference (in db) between the sound at the right and left ear as a function of the angle α, according to measurements by Sivian and White. In curves *1*, *2*, *3*, *4* the sound consisted of tones of 300, 500, 1 100 and 2 240 c/sec, respectively.

With tones lower than about 400 c/sec (wave length 110 cm) the difference in intensity is practically zero at all angles. If the wave length is much smaller than the head, absolute shielding takes place. With tones higher than about 10 000 c/sec (wave length 3 cm) the difference in intensity already reaches a maximum at a very small value of the angle α, and then no longer varies with α. Perception of direction by means of differences in intensity is most efficient with tones of about 1 000 - 2 000 c/sec, *i.e.* in the same frequency range in which the threshold of hearing is lowest. Considered therefore from the above-mentioned teleological point of view, one might say that the maximum of sensitivity of the ear is adapted to the size of the head.

We are not in general concerned with pure tones, but with sounds of a certain spectral complexity. For our purpose, stereophonic reproduction, speech is especially important. The average distribution of intensity of speech over the whole frequency spectrum is shown in *fig. 4*. With the help of this curve and the curves of fig. 3 the differences in intensity can be calculated of the sound occurring at each ear when a speaker is heard from different directions. The result is given in *fig. 5*. It may be seen that for angles between 0 and 50° the intensity difference in decibels increases practically linearly with the angle. The maximum intensity difference amounts to about 7 db. At the above-mentioned angle $\alpha = 3°$ which may be considered as the threshold value of sensitivity to direction, the intensity difference is only about $^1/_2$ db.

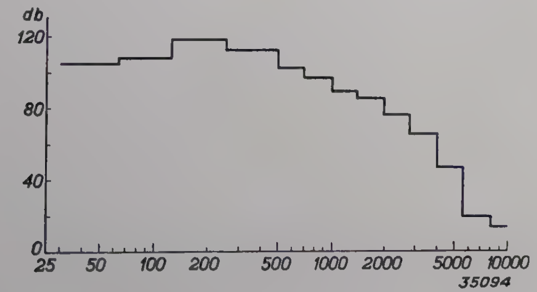

Fig. 4. Speech spectrum. The intensity (in db) per unit of frequency interval is plotted as a function of the frequency in c/sec.

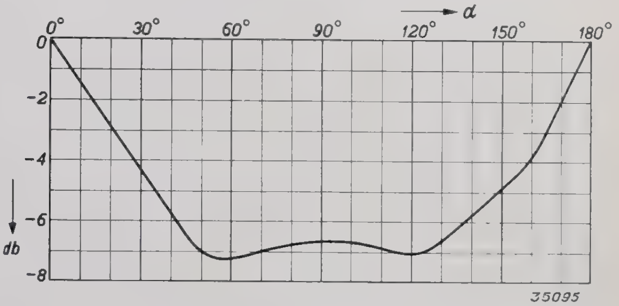

Fig. 5. Average intensity difference (in db) at the right and left ear as a function of the angle α upon hearing speech.

The dependence of the bending on frequency also results in a change of timbre. If for a certain direction of the source of sound (angle α) we plot the relative attenuation at one ear as a function of the frequency, we obtain the curves of *fig. 6*. The sound may be said to pass as it were through a filter in bending around the head, the filter having a frequency characteristic which may be very different for different angles α, as may be seen from fig. 6.

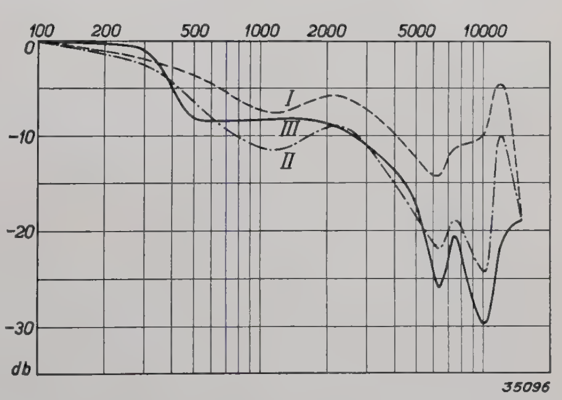

Fig. 6. Frequency characteristic of the bending around the head. Curves *I*, *II*, *III* refer to a source of sound at angles α 30, 60 and 90°, respectively.

Thus for different directions of the source of sound there appear differences in the quality of the sound which may also contribute to the perception of direction [5]).

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[5]) With the help of these differences in quality a judgment of direction is also possible to a certain extent with the use of only one ear.

Stereophonic reproduction

In order to retain the impression of direction in electrical transmission of sound, the sound must be delivered to the two ears of the listener with the correct relative time and intensity differences. This may be realized in a relatively simple manner by setting up in the recording room in the place of the absent listener an "artificial head" with two microphones in the positions of the ears. Each microphone, *via* its own amplifier and transmission line (channel), supplies one of two head phones at the ears of the listener. This solution of the problem has already been discussed in this periodical in the description of a hearing apparatus for a deaf person [6]). The artificial head there used is shown once more in *fig.* 7.

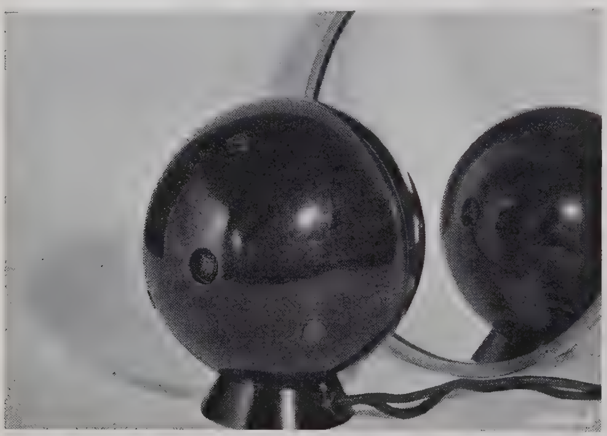

Fig. 7. A sphere with a diameter of about 22 cm may be used as an "artificial head". The microphones are situated at the extremities of a horizontal diameter.

We shall not expatiate upon the fact that two channels are needed for such transmission. This necessity will not present insoluble difficulties in many cases. In sound film for example, where the transmission line between the place of recording and that of reproduction is replaced by a sound track on a film, it is possible to make two sound tracks instead of one on the film, each of which corresponds to the sound for one ear. More objectionable however is the requirement that, on the principle mentioned every member of the audience in the cinema hall would have to wear a set of head phones. It would be preferable to use two common "telephones" for the whole auditorium, *i.e.* two loud speakers, one at each side. When this is done, however, there is immediately a deviation from the proposed principle in so far as both ears now receive sound from both loud speakers. In spite of this fact it has been found possible by experiment to obtain a fairly good stereophonic effect in this way. The factors concerned will be discussed in the following.

Differences in intensity and time in reproduction with two loud speakers

Fig. 8a shows an arrangement which can be used practically in a cinema. The two loud speakers are set up on either side of the screen, the reason for this will be given later. We shall consider the hearer to be situated in front of the screen in the middle, in the plane of symmetry of the arrangement. The artificial head is placed in an analogous position in the recording studio, *i.e.* in such a position that the vertical bisecting planes of artificial head and camera, respectively, coincide with each other, see fig. 8*b*. At a given position of the speaker (angle α) the intensities at the two "ears" of the artificial head differ by a factor p, which can be read off in fig. 5. The same ratio p also holds for the sound intensities which the two loud speakers in fig. 8*a* provide at the position of the listener. Let us assume that the left ear of the listener, looking straight ahead of him, receives an intensity I from the left-hand loud speaker. Then the right-hand loud speaker gives to the right ear an intensity of only pI. In addition however the right ear also receives an intensity qI from the left-hand loud speaker, where q is the attenuation factor which corresponds to the angle α of the direction of the loud speaker according to fig. 5. In the same way the left ear receives an intensity qpI from the right-hand loud speaker. Altogether, therefore, the left ear receives the intensity $I + pqI$, and the right ear the intensity $pI + qI$. The actual ratio between the intensities at the two ears of the listener is therefore not p, but

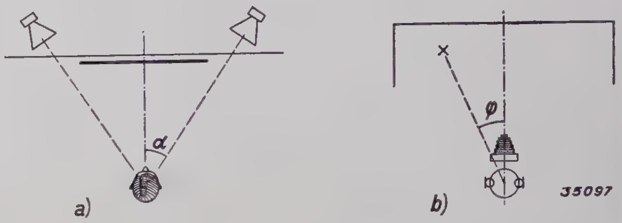

Fig. 8. a) Arrangement for stereophonic reproduction in a cinema. Two loud speakers stand at either side of the screen. A listener at a given distance from the middle of the screen sees the line joining the two loud speakers within an angle of 2α.
b) Arrangement of the artificial head in the studio. The perpendicular bisecting planes of camera and artificial head coincide. The speaker stands for example in the direction φ.

$$P = \frac{p+q}{1+pq} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

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[6]) See the article cited in footnote [1]).

In this equation p varies with the position of the speaker in the recording studio, while q is a parameter which depends upon the relative positions of the listener and the loud speakers. If $q = 0$, *i.e.* if each ear of the listener did not receive any sound from the "wrong" loud speaker, then $P = p$. This case, however, in which the intensity ratio p is exactly retained, cannot be realized with loud speakers, since according to fig. 6 q can never be made smaller than 0.2 (corresponding to an attenuation of 7 db). In the other extreme case where $q = 1$ *i.e.* when each loud speaker has the same effect for each ear, P becomes equal to unity according to equation (1), and there is no difference of intensity at the ears of the listener. For all the intermediate values of the parameter q, P is always greater than p, as a glance at *fig. 9* will show. *The difference in intensity at the ears of the listener is therefore always less than that at the "ears" of the artificial head.*

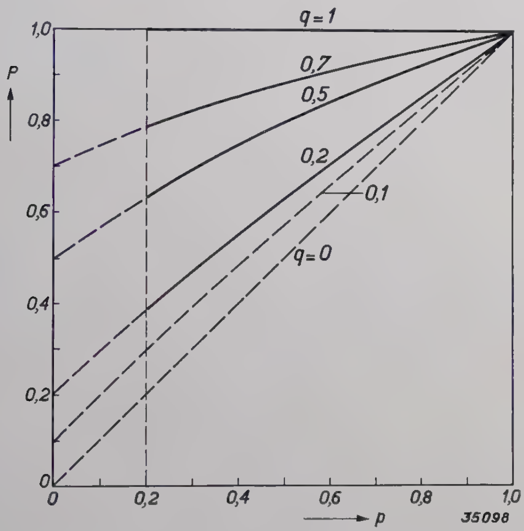

Fig. 9. The ratio P between the intensity of the sound at the right ear and that at the left ear of the listener (fig. 8*a*) as a function of the ratio p at the microphones of the artificial head (fig. 8*b*). The intensity ratio q between the sound contributions which one loud speaker makes to each ear enters as a parameter. q depends upon a, *i.e.* upon the relative positions of listener and loud speakers; it may however according to fig. 5 never be less than about 0.2. It may be seen, that P is always greater than p, *i.e.* the intensity difference is always smaller for the listener than for the artificial head.

Let us now consider the differences in time. In the case of the position of the speaker in the studio as represented in fig. 8*b* the left-hand microphone of the artificial head receives the sound slightly earlier than the right-hand one. The difference amounts t sec. [7]) The left ear of the listener (fig. 8*a*) will then also receive the sound from the left-hand loud speaker t sec earlier than the right ear receives the sound of the right-hand loud speaker. But a moment later (T sec) both ears receive the sound (weaker by a factor q) from the "wrong" loud speaker, and in this case the right-hand ear is served t sec earlier. This is represented schematically in *fig. 10*. It may be seen that both ears perceive a time difference of t sec between the sound contributions I and $p\,I$, respectively, and that this whole impression is repeated, weakened by a factor q and with reversed time difference, T sec later as a kind of echo. This echo causes a slight vagueness in the directional effect, but it may be neglected in our considerations, especially when $T > t$, which is usually the case.

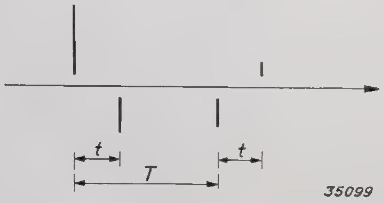

Fig. 10. Above the time axis, the moments of arrival of the sound contributions at the left ear, below the time axis, the same for the right ear. The time difference t corresponds to the angle φ, (fig. 8*b*), the difference T to the angle a (fig. 8*a*). The length of the vertical lines indicates approximately the intensities which the four contributions to the sound may assume.

The result is that the listener perceives an intensity difference P and a time difference t, while, if he stood at the position of the artificial head, he would perceive a (greater) intensity difference p and an (equal) time difference t. As a perception of what direction will the listener now interpret the differences P and t?

No direct answer to this question is possible, since the combination P, t never occurs in "natural" directional hearing as learned from experience. With a given direction with respect to the head there corresponds not only a given intensity difference, but also a definite, unambiguous time difference. It might be supposed that the ear is so accustomed to this unambiguousness, that combinations deviating therefrom would only cause a feeling of confusion. This is fortunately not the case, as will be shown in the following.

The cooperation of intensity and time differences

In order to be able to understand the cooperation of intensity and time differences the following experiments were carried out in this laboratory. The two loud speakers were set up behind a screen as in *fig. 11*, while on a horizontally placed wooden bar in front of the screen a scale was marked off.

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[7]) For the following considerations it is essential that the reproduction of speech should always be kept in mind. If listening tests are carried out with pure tones or in general with tones having a periodic vibrational form, one can no longer speak unambiguously of a "time of arrival". It is actually found possible in such cases to cause serious confusion of the impression of direction.

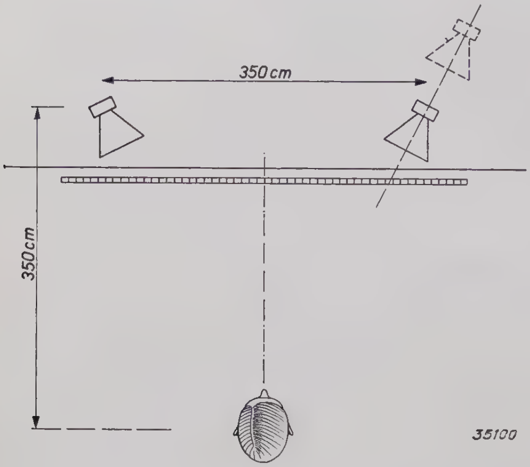

Fig. 11. Arrangement of the loud speakers in the experiments concerning the cooperation of time and intensity differences.

a) Differences in intensity were caused in the sound of the loud speakers. This was done by regulating the volume of one loud speaker with a calibrated potentiometer, while both of them were reproducung the same gramophone record. The listener was then found to receive a fairly sharp impression of direction, and could localize the fictitious source, the "sound image", on the scale with a reproducibility of a few centimeters. In *fig. 12* the angular rotation of the "sound image" so obtained is plotted as a function of the ratio of intensities (in db). At the same time the angle is given (broken line curve) which should correspond to each difference in intensity according to fig. 5. It may be seen that a difference in intensity alone always causes a perception of the angle which is 10 per cent less than that which occurs in natural directional hearing, where the "added" time difference is also present.

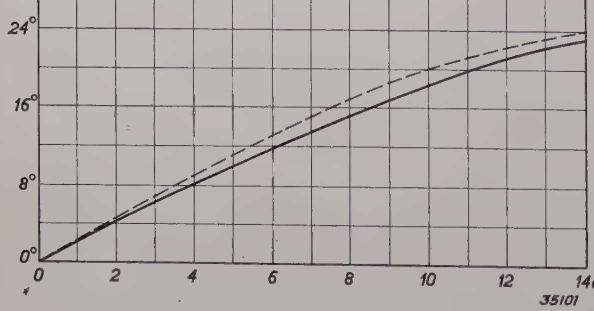

Fig. 12. Angular rotation of the "sound image" away from the middle position when only intensity differences are applied. The broken line curve gives the angles in the case of natural directional hearing, where the intensity difference is always accompanied by an "added" time difference.

b) In the following experiment time differences alone were investigated. These were caused in the sound of the two loud speakers, which were again reproducing the same gramophone record, by shifting one of the loud speakers along the line joining loud speaker and listener. The volume of the sound was so adjusted that the intensities of the two loud speakers always remained the same for the listener. Again it was found that the listener obtained a certain impression of direction, which has been plotted in *fig. 13* as a function of the time difference. The broken line curve indicates the angle which, according to fig. 2, would be observed in natural directional hearing (thus in collaboration with the added difference in intensity). It is interesting to note that the sense of hearing is able to localize a sound when the time differences are greater than ever occur in natural directional hearing, and which time differences therefore, the ear can never actually have "learned" to interpret as indicating direction. For the rest the curves show qualitatively (at least for the range of angles investigated in the experiments) that the possibility of normal perception of direction of sound depends mainly upon differences in intensity, as was already indicated by fig. 12.

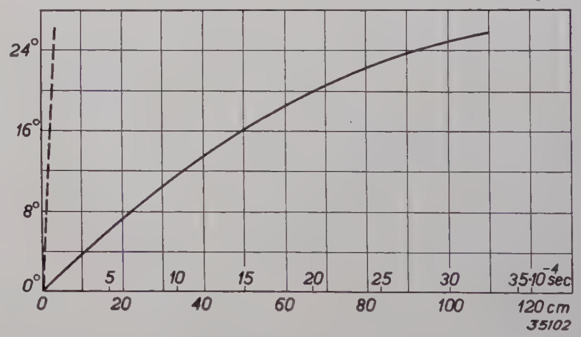

Fig. 13. Like fig. 12 but with time differences alone. The broken line curve refers again to natural directional hearing. The differences in length of path are also indicated on the abscissa. It is remarkable that localization is found to be possible even with differences in length of path which are much greater than the distance between the ears.

c) If differences in intensity and time occur simultaneously, it is found that the angle observed can always be calculated from the data of figs. 12 and 13, in the following way. As a function of the time difference the intensity difference is plotted which would cause the same angular rotation of the "sound image". We then obtain a practically linear relation (see *fig. 14*). As a result every time difference may be expressed unambiguously as an equivalent intensity difference, and *vice versa*. If we now add this equivalent intensity difference to that already present, and find in fig. 12 the angle corresponding to the total intensity difference, it is found to agree, within the limits of error of the measurement, with the experimentally determined angular rotation of the "sound image" [8]).

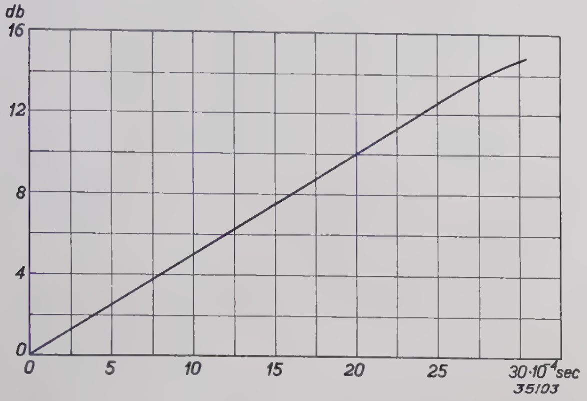

Fig. 14. For each time difference the intensity difference is plotted which causes the same angular rotation of the "sound image".

This additivity must of course also hold for normal directional hearing, where not only **any** difference in time and intensity are combined, but in which a time difference is "added" to every intensity difference. If we convert the added time differences according to fig. 14 into equivalent intensity differences, and add these to the actual intensity differences, the total always gives the angle actually observed, within the limits of error of the measurement. This is shown in *fig. 15*.

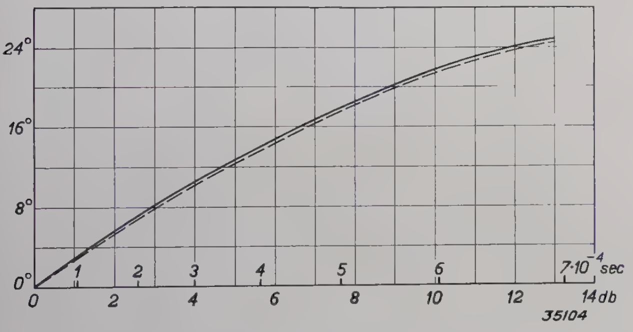

Fig. 15. Perception of angle in normal directional hearing (full line curve), in which an added time difference (indicated on the abscissa) occurs for each intensity difference. By conversion into an equivalent total intensity difference with the help of fig. 14, and then finding the corresponding angle in fig. 12, the broken line curve is obtained, which agrees satisfactorily with the full line curve.

The position of the "sound image"

With the data of figs. 12 and 14 it is now possible to answer the above proposed question as to the directional impression which will occur with any combination P, t of intensity and time differences. If we allow the speaker in fig. 8*b* to move over a given traject in front of the artificial head, then for every position we can calculate the differences P and t, and from them the position at which the listener in fig. 8*a* will preceive the "sound image" to be situated. In *fig. 16* the relation so obtained between the original angle and that observed is given for a particular arrangement. As long as the speaker remains within an angle of about 120° a satisfactorily linear "focussing" of the movement of the source of sound is obtained on the screen [9]).

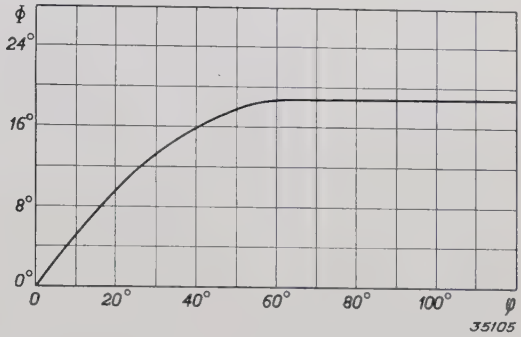

Fig. 16. Angular rotation Φ of the "sound image" as a function of the angle φ of the speaker with respect to the artificial head (fig. 8*b*).

Until now we have always assumed the listener to be situated at a definite place in the plane of symmetry of the loud speakers. In a cinema, however, a large area is actually occupied by the audience. It is clear that for different positions the perception of direction in stereophonic reproduction will be quite different. According to the method applied above, we could calculate the stereophonic effect for each seat. In order however to obtain a general idea, we have carried out a number of listening tests, the results of which are given in *fig. 17* and *fig. 18*. For three places *2*, *3*, *4*, which are indicated in fig. 17, fig. 18 shows how the "sound image" moves, if, for the listener at place *1*, it shifts over a given distance of the screen. For seats more to one side the "focussing" shrinks, the "sound image" moves a shorter distance than the speaker in front of the artifical head. In the shaded region in fig. 17 the "focussing" has shrunk so much that the listeners in these seats observe practically no stereophonic effect at all. By the arrangement of the loud speakers at opposite sides of the screen with the greatest possible distance between them (to make the factor q in equation (1) small), the shaded region of fig. 17 is restricted as much as possible.

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[8]) In the same way of course the intensity difference can be converted according to fig. 14 into an equivalent time difference, and the total angle may then be read off in fig. 13.

[9]) In the above it has always been assumed that the listener looks straight ahead. If he turns his head, then the condition must be satisfied, that the "sound image" remains stationary on the screen. This is found to be the case to a sufficiently close approximation.

In order not to make the intensity differences confused, it is advisable that the sound radiation of the loud speakers should be constant within the angle at which the loud speaker faces the audience. Outside this angle the loud speakers should radiate as little sound as possible, since this sound reaches the audience after one or more reflections in the form of reverberation, by which the sharpness of the sound image is unfavourably affected.

The two amplifiers and loud speakers which are used in reproduction may not differ in quality of reproduction. Otherwise there is a tendency for the listener to interpret the differences in quality as an indication of direction (see above), *i.e.* to concentrate his attention in the direction of the better loud speaker.

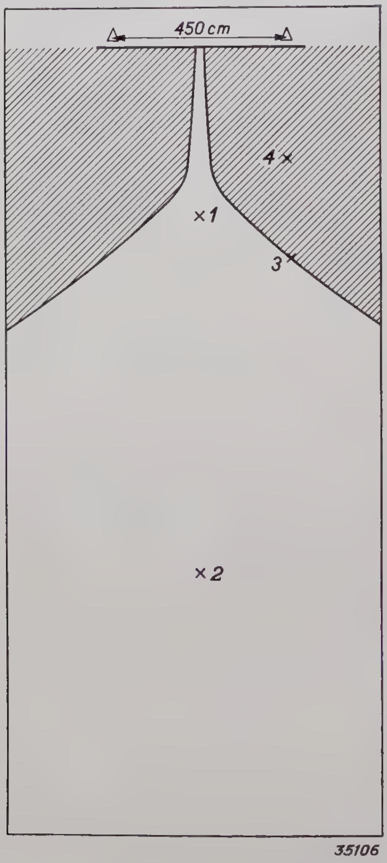

Fig. 17. In the seats situated in the shaded regions the listener observes a maximum displacement of the "sound image" over only half the width of the screen, so that the stereophonic effect is not sufficient here.

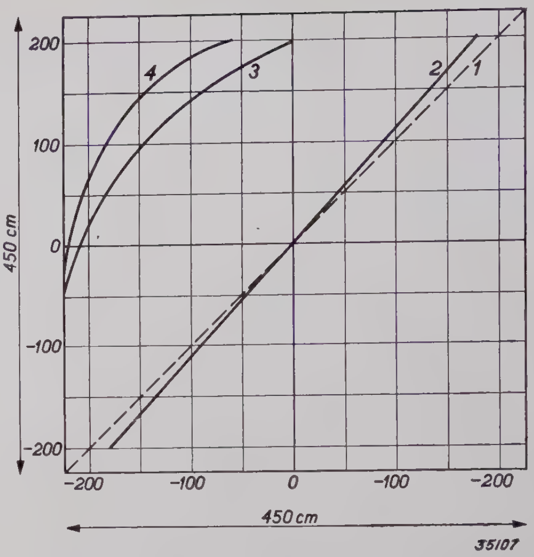

Fig. 18. If the "sound image" for the listener at place *1* (fig. 17) is displaced over the whole length of the screen (450 cm, indicated as abscisse), the listeners at the places *2*, *3*, *4*, in fig. 17 only observe the displacement of the "sound image" indicated as ordinates in the figure.

In sound reproduction in cinemas use is at present commonly made of separate loud speakers for the high and low frequency ranges (above and below about 300 c/sec, respectively). We have already seen that tones with frequencies below 300 c/sec are practically incapable of arousing any perception of direction. Therefore for stereophonic reproduction it is only necessary to set up two loud speakers for the high tones at either side of the screen, while the low tones can be reproduced by a single loud speaker placed at any desired position, for instance behind the middle of the screen.

THE REPRODUCTION OF HIGH AND LOW TONES IN RADIO RECEIVING SETS

by V. COHEN HENRIQUEZ.

621.396.667: 621.396.645.37

In this article the question is considered as to what is the best frequency characteristic for a receiving set when account must be taken of side-band interferences caused by transmitters with frequencies which are very close to that to which the set is tuned. Since the intensity of these interferences may differ very widely, it is desirable to make the characteristic adjustable. It is described in detail how, by means of variable inverse feed-back, it is possible to obtain the desired adjustability of the frequency characteristic.

Introduction

If there were only the electromagnetic field of a single transmitting station present at the receiving aerial, speech and music could be transmitted practically undistorted. The actual situation, however, is that in general a large number of transmitters are in operation at the same time, and their wave lengths are so chosen that two successive carrier waves have an average frequency difference of 9 000 c/sec. When the amplitude of the vibration transmitted is modulated in the rhythm of a sound vibration, then in addition to the carrier wave there are numerous other waves (the so-called side bands), whose frequencies occupy a region which has a width on either side of the carrier-wave frequency equal to the maximum frequency occurring in the sound. When two adjacent transmitters are modulated with sound frequencies higher than 4 500 c/sec, the frequency regions used for the two transmissions will overlap each other (*fig. 1*), so that it is impossible to receive all the frequencies of one transmission without interference by the other. If, for example, the interfering transmitter is modulated with a frequency of 6 000 c/sec, a wave occurs whose frequency differs by only 3 000 c/sec from the desired carrier wave, and which will be heard as a tone of 3 000 c/sec [1]. In general it may be stated that a modulation of the interfering transmitter with a frequency ν is heard as a tone of the frequency $9\,000 - \nu$, which results in the well-known crackling effect (side-band splash), usually accompanied by a continuous whistle of 9 000 c/sec from the interfering carrier wave itself.

The side-band interference and the whistle can be practically eliminated by changing the reproduction characteristic of the set in some way or other so that the reception of high tones, especially that of 9 000 c/sec is sufficiently weakened. It is true that the quality of reproduction of the desired transmission is hereby affected, but it is found nevertheless that by a suitable weakening of the reproduction of the high tones a result can be achieved which, in the presence of the interfering transmitter, is judged to be better than an absolutely faithful reproduction.

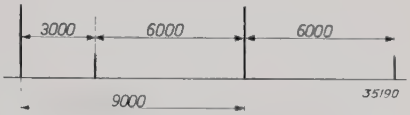

Fig. 1. The carrier waves of two adjacent transmitters have a frequency difference of 9 000 c/sec. If the carrier wave of the interfering transmitter is modulated with a signal of 6 000 c/sec a differential frequency of 3 000 c/sec occurs between one of the interfering sidebands and the carrier wave to which the set is tuned.

The reproduction of low frequencies is also subject to restrictions which have their basis in aesthetic requirements. The loud speaker must be housed in a receiving set whose cabinet may not be too large. If one applies to the loud speaker a current of constant effective value and steadily decreasing frequency, the sound pressure produced in the room will fall suddenly when the frequency falls below the resonance frequency of the radio cabinet. This latter is higher, the smaller the cabinet, and amounts to about 200 c/sec. At the resonance frequency itself there is a peak of sound pressure. The irregular shape of the loud speaker characteristic can be compensated within certain limits in the electrical part of the apparatus. It is however impossible as well as unnecessary to stretch the frequency band reproduced to frequencies lower than about 50 c/sec.

In this article we shall study the shape of characteristic which forms the most satisfactory compromise, and the method by which this characteristic is realized in modern radio receiving sets.

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[1] The low-frequency vibrations, which occur in the detection of the high-frequency signal, have frequencies equal to the differential frequencies between all the vibrations present in the high-frequency signal. If the signal of one frequency (the carrier wave) is appreciably stronger than all the others, practically only differential frequencies between carrier wave and the rest of the signals (side bands) occur. These give rise to the desired low-frequency signal and sometimes to side-band interference. They must not be confused with the sound of the adjacent transmitter which occurs when not only a side-band but also the carrier wave of the adjacent transmitter acts with considerable intensity on the detector.

Choice of reproduction characteristic

The most satisfactory form of frequency characteristic may vary very much according to the nature of the transmission and the relative strength of the interfering transmitters. In speech, for example, frequencies above 4 000 c/sec are almost entirely absent, so that the frequency characteristic might be allowed to fall to zero above 4 000 c/sec without too unfavourable effects on the reproduction. Only modulation frequencies of the interfering transmitter above 9 000 — 4 000 = 5 000 c/sec would then produce side-band interference, and this limitation may be enough to eliminate side-band interference.

In transmission of music the combatting of side-band interference without seriously impairing the quality of the reproduction is much more difficult. It is true that in this case also the frequencies above about 4 000 c/sec can be weakened without too unfavourable effects on the quality of the reproduction, but a complete suppression of these frequencies is certainly undesirable. One must therefore not proceed farther with the weakening of the reproduction of certain frequencies than is absolutely necessary for the suppression of the interferences at those frequencies. In speech as well as in music the largest part of the intensity is radiated at frequencies from 200 to 1 000 c/sec, at higher frequencies the intensity decreases rapidly per unit of frequency interval. In the case of side-band interference, where the intensity distribution of the interfering transmission is reflected with reversed frequency scale (9 000-ν), the intensity will increase with increasing frequency, so that the reproduction must be more and more weakened with increasing frequency in order to keep it free of interference.

In a given case for example we find that the above mentioned compromise is represented by curve *a* of *fig. 2*. The side-band interference with this reproduction characteristic was equally intense for all the high frequencies which are reproduced in a partially weakened form, and this intensity was just below the threshold value of the ear. As may be seen the low frequencies are also weakened. This is found desirable in order not to disturb the balance between high and low tones by the weakening of the high tones alone.

If the intensity of the interfering transmitter becomes fifty times lower, the high frequencies then need less weakening. The amplification can then be kept constant over a larger region. Only those frequencies which had originally to be weakened more than fifty times in order to keep the corresponding interferences below the threshold value, must now still be weakened. Because of the fact that the high tones are less weakened, the low tones can now be better reproduced without the timbre becoming too low, so that we now obtain curve *b* which provides a considerably better reproduction than curve *a*.

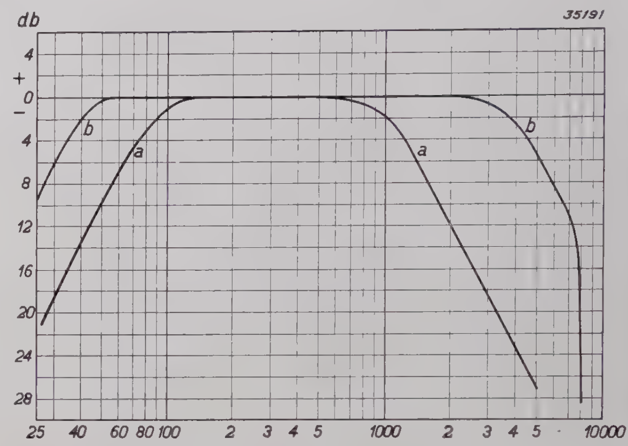

Fig. 2. Most satisfactory reproduction characteristic in the presence of side-band interferences. Toward high frequencies the amplification decreases in such a way that the remaining side-band interferences lie just below the threshold value in every frequency interval. Toward low frequencies the characteristic is also allowed to fall in order to compensate to some extent for the lowering in timbre which occurs due to the cutting off of the high frequencies.
a) Empirically found characteristic in the presence of strong side-band interference. b) Characteristic which can be derived therefrom if the interfering transmitter is 100 times weaker.

It has been found by experiment that the average slope which the curves in fig. 2 must have at high frequencies, in order to keep the side-band interferences just below the threshold value in all frequency regions, must be —3. This means that the amplification for high frequencies must be inversely proportional to the third power of the frequency.

The desired frequency characteristic is therefore horizontal up to a given limiting frequency, and then falls with the third power of the frequency [2]). In order to eliminate the continuous whistle of 9 000 c/sec, caused by the carrier wave of the interfering transmitter, together with the side-band interferences, it is furthermore necessary to weaken at least 30 dB more at these frequencies than is necessary for the suppression of the side-band interferences.

Consequences for the frequency characteristic of the different parts of the receiver

By the total frequency characteristic of a receiver we mean the relation between the effective sound pressure and the effective input voltage of the corresponding sideband, represented as a function of the frequency. In the case of a superheterodyne receiver this frequency characteristic is the product of the high-frequency characteristic, the middle-frequency characteristic, the low-frequency characteristic and the reproduction characteristic of the loud speaker. Each of these four factors depends upon the frequency, and in principle it is a matter of indifference which factor is influenced by special means to obtain the desired characteristic [3]). Usually the reproduction characteristic is influenced in the high-frequency as well as in the low-frequency part by filters, the last of which has an adjustable band width. A so-called "tone regulator" is also introduced in the low-frequency part to make it possible to regulate the reproduction of the high tones.

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[2]) It is found that the transition from the flat portion to the sloping portion of the characteristic may not take place too rapidly (see fig. 2), because otherwise the reproduction becomes somewhat harsh.

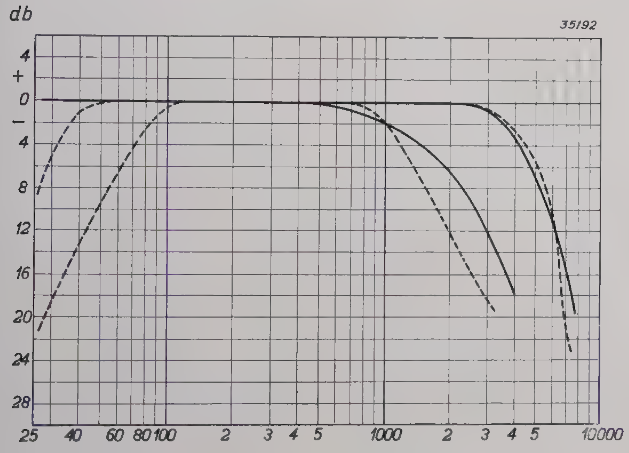
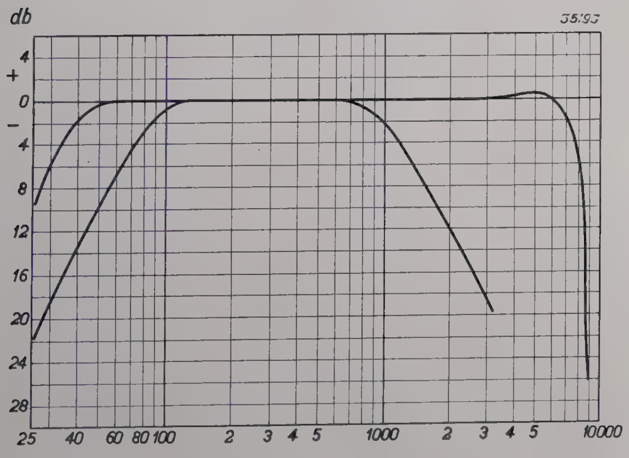


Fig. 3. a) Full lines: reproduction characteristic of the high and middle-frequency part of a receiver at the widest and narrowest position of the variable band filter. Broken lines: desired reproduction characteristics (figs. 2*a* and *b*).



b) Reproduction characteristics which the low-frequency part of the set together with the loud speaker should have in order to obtain the desired characteristics for the whole apparatus at the widest position of the band filter.

In *fig. 3a* the full lines give the reproduction characteristic of the high and middle frequency part for a superheterodyne receiver of the usual type. The two curves refer to the two extreme adjustments of the band width. It may be seen that at high frequencies the curves show some similarity with the desired characteristics according to fig. 2 (broken line curve). The curved section between the constant and the descending part of the curve is however more gradual than is necessary or desirable.

In order to gain improvement in this respect one may try to compensate the difference between the characteristic obtained and that desired in the low-frequency part of the apparatus. It is advisable for this purpose to adjust the band filter to the greatest band width, and make the low-frequency reproduction characteristic variable [4]). The desired shape is represented in fig. 3*b*; it should therefore be obtained by means of low-frequency amplifiers and loud speaker together.

The reproduction characteristic of a loud speaker of good quality changes only very gradually in the region of high frequencies, so that in a qualitative discussion of the total reproduction characteristic it needs not be taken into account. At low frequencies, however, as stated above, greater irregularities occur which may be ascribed to a resonance of the air in the cabinet of the loud speaker.

Fig. 4 shows an example of a loud speaker characteristic. The sensitivity of the loud speaker, *i.e.* the ratio between the sound pressure obtained and the current through the coil, is about constant for frequencies above 400 c/sec. Between 400 and 200 c/sec it rises, and at 200 c/sec it reaches a maximum due to the resonance of the volume of air in the cabinet. At 60 c/sec a second maximum occurs due to the characteristic resonance of the vibrating loud speaker coil. The shape of the characteristic for lower frequencies is of little importance for the quality of reproduction.

In order to compensate the irregularities of shape in the low frequencies and to obtain the frequency characteristic drawn in figs. 2*a* and *b* throughout the whole range of frequencies, the low-frequency characteristic must have a shape like that shown in *fig. 5*. Since the reproduction characteristic of the loud speaker decreases below 900 c/sec with decreasing frequency more rapidly than is desirable for the total frequency characteristic, the sensitivity of the amplifier must in that region increase with decreasing frequency. This course is interrupted by a minimum at 70 c/sec, corresponding to the above-mentioned resonance of the loud speaker. The rapidity of the increase must change with the intensity with which the low tones must be reproduced, and the latter as stated above runs parallel with the intensity of reproduction of the high tones. The two curves, as in fig. 2, correspond to the chosen compromise for the cases of a very weak and a very strong interference, respectively, by a transmitter in the adjacent frequency band.

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[3]) This is not entirely a matter of indifference, because in no case may two carrier waves act with appreciable intensity on the detector (see footnote [1])). Moreover, due to the curvature of the valve characteristics, undesired effects occur when two transmitters are present simultaneously in appreciable intensity. For example, the carrier wave of the transmitter to which the set is tuned may undergo a modulation in the rhythm of the modulation of an interfering transmitter (cross modulation). In that case the interfering transmitter can no longer be made inaudible, even if the carrier wave and side bands of the interfering transmitter are entirely eliminated further along in the set.

[4]) In the case of unusually strong interferences the band width can still always be made smaller.

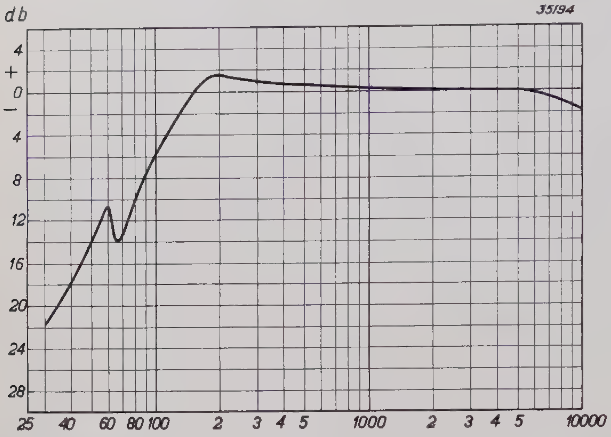

Fig. 4. Reproduction characteristic of a loud speaker (sound pressure as a function of the frequency with constant current). The first maximum is due to the resonance of the loud-speaker coil, the second, weak maximum is due to a resonance of the volume of air in the cabinet.

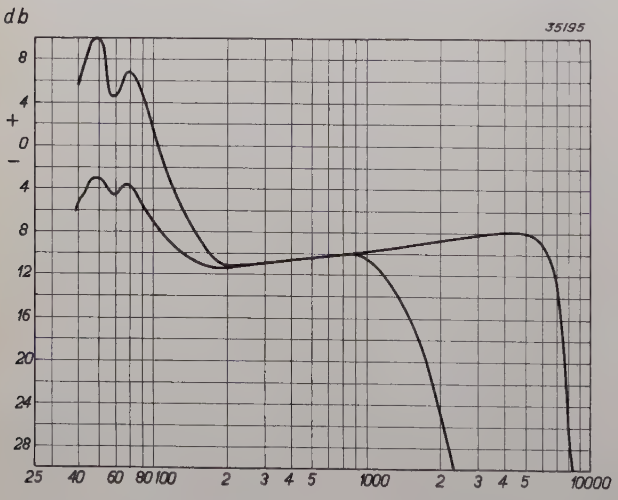

Fig. 5. Frequency characteristic (relation between output current and input voltage), which the low-frequency part of the set should have in order, together with the loud speaker, to provide the characteristic given in fig. 3*b*. The upper and lower curves of the figure correspond to the upper and lower curves respectively of fig. 3*b*.

Practical realization of the desired frequency characteristic

A commonly used method of producing a variable weakening of the high tones in the low frequency part of a receiver, consists in bridging the primary terminals of the loud speaker transformer by a condenser with a variable resistance in series. This method is, however, unsuitable for our purpose. When the maximum weakening of the high tones is not applied, and when therefore the variable resistance is not made equal to zero, the impedance of the *R-C* circuit does not approach zero with increasing frequency, but retains a finite limiting value. This means that the weakening obtained in this way does not increase to an unlimited extent with increasing frequency, but also reaches a limiting value. In *fig. 6* the frequency characteristics are given which may be achieved at different values of the series resistance, and it may be seen that they do not correspond at all to our requirements (fig. 5). If, instead of the resistance, the capacity should be made variable, less unsatisfactory frequency characteristics could be obtained. We shall not go into this matter here, since a solution which is practically simpler can be found in the application of variable inverse feed-back.

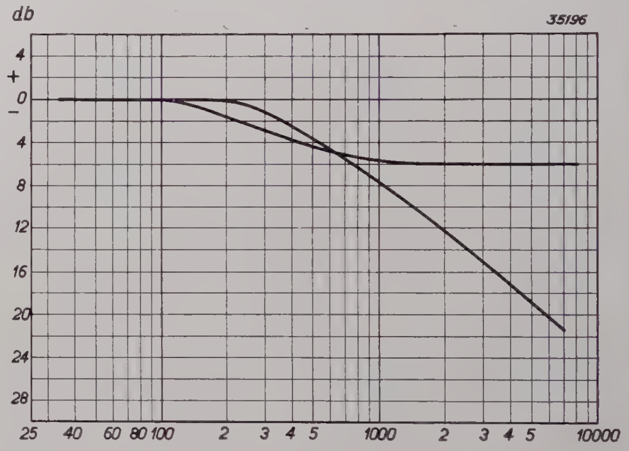

Fig. 6. Frequency characteristic of a low-frequency amplifier when an *R-C* circuit is connected across the input terminals of the loud-speaker transformer as a "tone-regulator", for $R = 0$ and for the maximum value of R. The curves show little similarity with the desired curves of fig. 5.

Variable inverse feed-back

It has already been shown in this periodical [5]) that many properties of a receiving set can be varied within wide limits by the use of inverse feed-back. In particular inverse feed-back makes it possible to give the frequency characteristic of an amplifier almost any desired form, by varying the strength of the feed-back as a function of the frequency in a suitable manner.

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[5]) "Inverse feed-back" Philips techn. Rev. **2**, 289, 1937.

The amplification μ of an inverse feed-back amplifier has repeatedly been given in this periodical 6), and is:

$$\mu = \frac{a}{1 + a\beta},$$

where a is the amplification without inverse feed-back and β is the part of the output voltage which is conducted back to the input side. If the inverse feed-back is so arranged that β increases rapidly and in a regulable manner with increasing frequency the desired shape of frequency characteristic can be obtained. As an example, *fig.* 7 shows the variation of the amplification for an inverse feed-back factor:

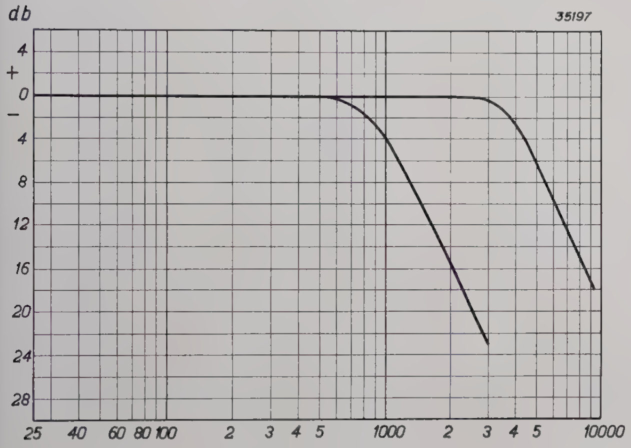

Fig. 7. Frequency characteristic of an inverse feed-back amplifier with an inverse feed-back factor for two values of a. The curves show some similarity with those of fig. 5.

$$\beta = a\,\omega^3.$$

The frequency characteristic is then given by:

$$\mu = \frac{a}{1 + a\,a\,\omega^3};$$

This is plotted in fig. 7 for two values of a and has about the desired form, although the finer details of fig. 5 are still lacking.

A possibility of obtaining the desired regulable increase in the inverse feed-back factor as a function of the frequency is given by the arrangement represented in a simplified form in *fig.* 8 of a low-frequency amplifier. The voltage from the output side is conducted *via* two channels to the cathode connection of the first amplifier valve (and farther to earth). This takes place from the secondary side of the loud speaker transformer *via* Z_1 and Z_2 and from the primary side of the loud speaker transformer *via* C, R, L, Z_2.

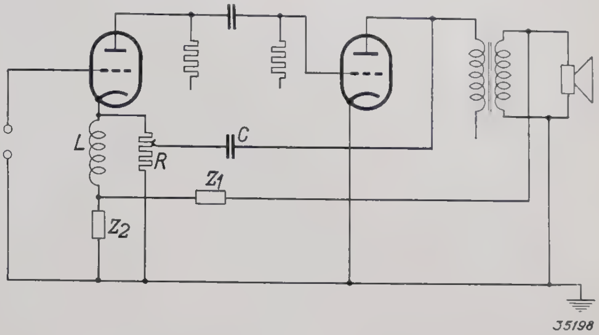

Fig. 8. Simplified connections of a low-frequency amplifier of two stages with variable inverse feed-back, whose intensity increases approximately in the desired manner with increasing frequency.

Although the voltage at the primary side is much greater, at low frequencies only the inverse feed-back of the secondary side is effective, because the condenser C passes practically no current. The inverse feed-back voltage of the secondary is divided between the impedances Z_1 and Z_2, which are so chosen that the strength of inverse feed-back gradually decreases with increasing frequency. The inverse feed-back along the second branch is, however, always more effective with increasing frequency. There are two reasons for this. In the first place at a constant amplitude of the input voltage the voltage at the primary side of the transformer increases with increasing frequency, due to its spreading selfinduction and the increasing impedance of the loudspeaker. In the second place a larger and larger part of the feed-back voltage acts on L, since the impedance of C decreases and that of L increases. The result of the described variation of the inverse feed-back along the two branches is that with increasing frequency a slight increase in amplification is obtained which is followed by a rapid fall. This agrees with the desired characteristic according to fig. 5.

In order to make the variation regulable at high frequencies the resistance R is provided with a sliding contact. When the contact is at the lowest point the feed-back current through C flows directly to earth, so that there is no inverse feed-back. When the contact is at the highest point the inverse feed-back is at a maximum; practically the whole current flows through L and Z_2 since the impedance of this connection to earth is small with respect to R. Thus

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6) Philips techn. Rev. **1**, 264, 1936 and footnote 5).

by moving the contact the degree of inverse feed-back can be regulated continuously.

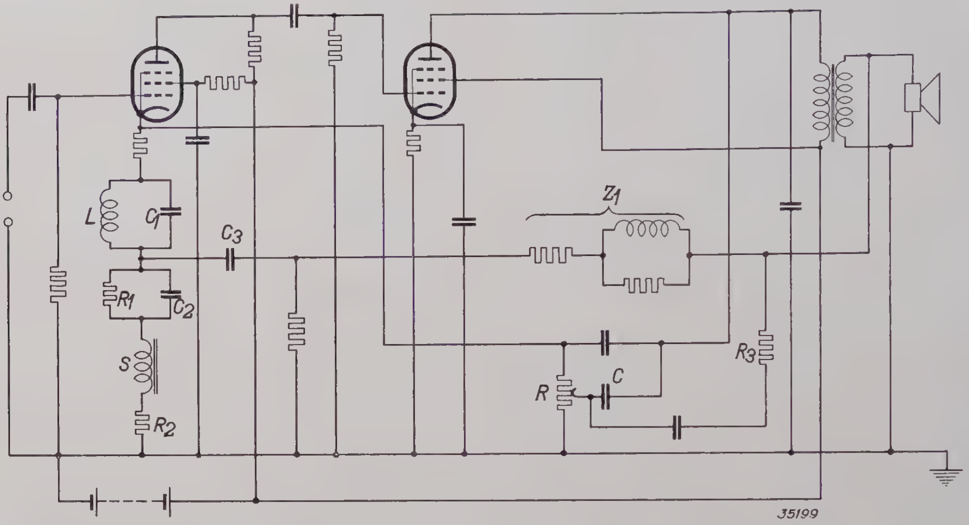

Fig. 9. Complete connections of the variable inverse feedback. In contrast to the simplified connections of fig. 8, these connections also give the desired shape of frequency characteristic (fig. 5) at low frequencies, and moreover provide that at 9 000 c/sec the reception as a whole is less suppressed.

In *fig. 9* may be seen the complete connections of the low-frequency amplifier whose principle is sketched in fig. 8. The connections contain a number of elements which have not yet been mentioned and which serve to give the reproduction characteristic the desired shape in the finer details. The self-induction L is replaced by a blocking circuit LC_1, which is tuned to a frequency of 9 000 c/sec. At this frequency therefore the inverse feed-back becomes very intense, so that the amplification of this frequency is subject to the desired extra weakening.

The capacity C_2, together with the capacity C_3 and the choke S, provide for the desired shape of reproduction characteristic at very low frequencies [7]). C_2 is so chosen that at 50 c/sec a series resonance of C_2 and S occurs. At this frequency therefore there is only the impedance R_2 left in the cathode connections, and this is relatively small so that only slight inverse feed-back occurs and the amplification has a maximum.

For frequencies above 50 c/sec the connection in series of S and C_2 has an impedance of an inductive nature. At a definite frequency, which lies just above the resonance of the cabinet, series resonance occurs between this inductive impedance and the capacity of C_3. The feed-back voltage then becomes very large and the amplification thus has a minimum which compensates the maximum caused by the resonance of the cabinet. The resistance R_2 serves to damp the series resonance and thereby to adapt it to the character of the fairly well damped resonance of the cabinet. Finally, by means of the resistance R_3 provision is made that the adjustable part of the inverse feed-back is also effective at low frequencies. By this means the low tones are also weakened in increasing degree with increasing weakening of the high tones, which as we have seen is desirable.

In *fig. 10* the frequency characteristic obtained is given for the extreme positions of the tone regulator. A comparison with the curves of fig. 5 shows how closely the desired goal has been achieved.

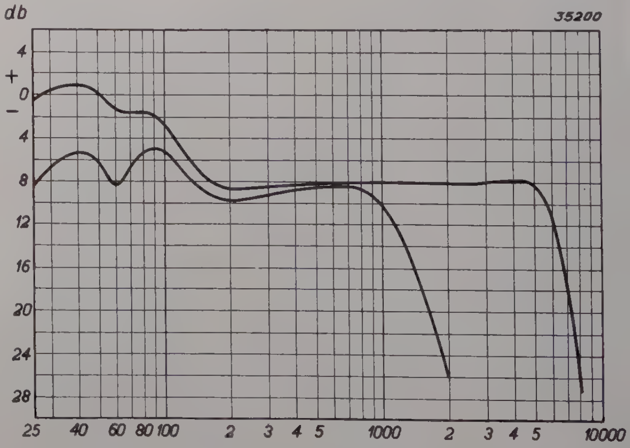

Fig. 10. Frequency characteristic of an amplifier with connections according to fig. 9, for the extreme positions of the variable inverse feed-back. The desired shape of fig. 5 is very closely approached.

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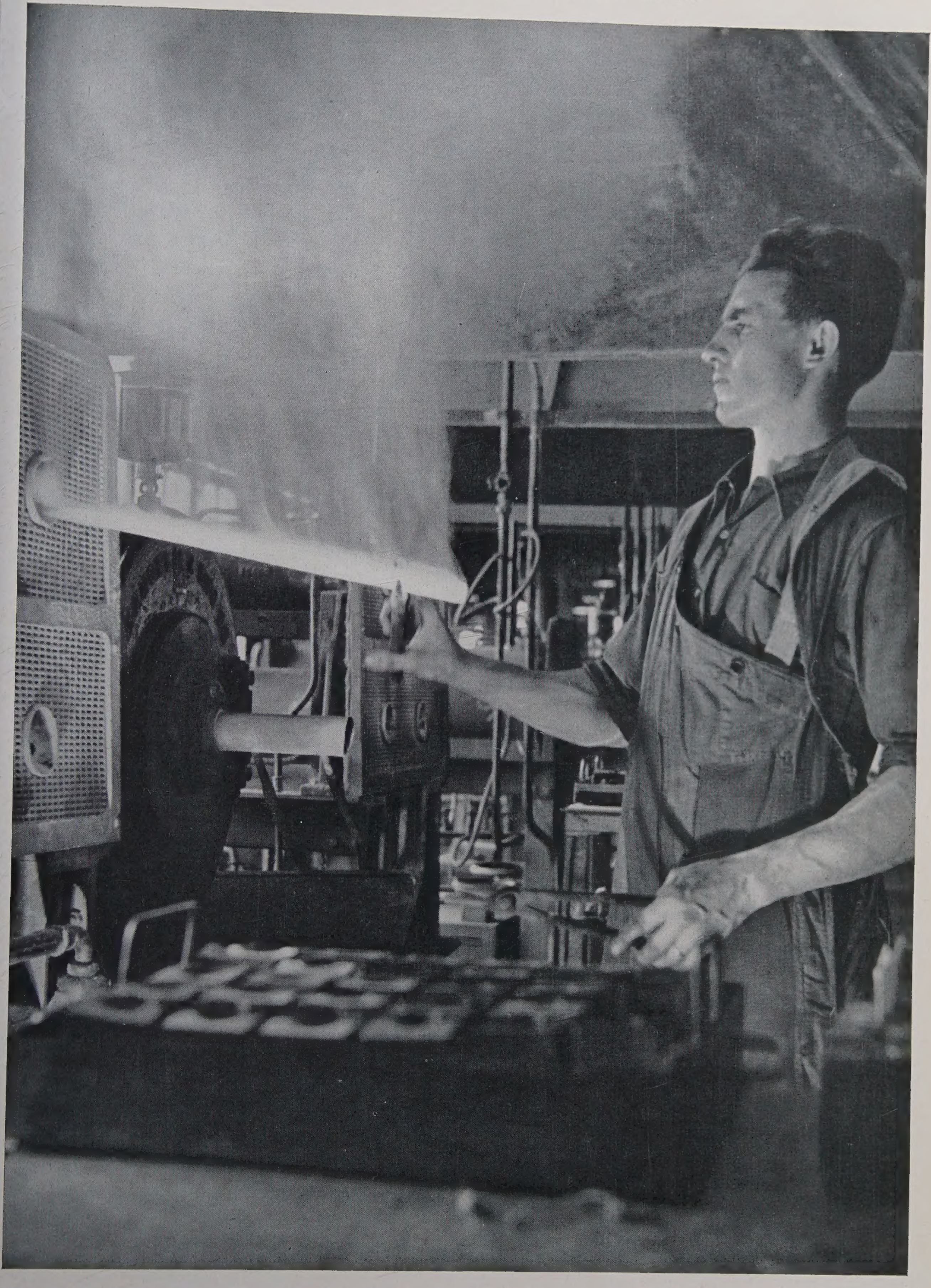
[7]) The resistance R_1 serves in the usual way to give the cathode a positive D.C. voltage with respect to earth, so that the control grid takes on a negative bias with respect to the cathode. For our considerations the resistance plays no part, since its value is large compared with the impedance of C_2.

THE SWAGING OF TUNGSTEN RODS



The sintered rods are heated in the electric furnace and gradually introduced into the swaging machine. In this way their diameter is reduced and their length increased.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1455: J. H. Gisolf: The dielectric losses of irradiated zinc sulphide phosphors (Physica **6**, 918-928, Oct. 1939).

The changes in dielectric constant and dielectric losses were measured for zinc manganese sulphide upon irradiation with electromagnetic waves of various separate frequency regions between 10^3 and 1.5×10^7 c/sec. Upon irradiation with the long wave absorption bands of the manganese ion itself, no change is found in the dielectric properties, so that the luminescence thereby occurring is indeed caused only by excitation and ionization of the separate atoms. Upon irradiation with frequencies at which the crystal lattice may begin to oscillate, the dielectric properties do however change considerably. With oscillations slower than 1 000 c/sec such great space charges occur in the crystal that the counter fields thereby generated compensate the externally applied fields so completely that the losses are immeasurably small. In the long wave tails of the crystal absorption the appearance of phosphorescence phenomena must also be taken into account, so that the losses depend upon the frequency in a complex manner. In the ultraviolet region of the crystal absorption an absorption coefficient of about 5×10^4 is calculated at a wave length of 3 100 Å from the measurements of the dielectric losses.

1456: J. H. de Boer and H. Bruining: Secondary electron emission. VI. The influence of externally adsorbed ions and atoms on the secondary emission of metal (Physica **6**, 941-950, Oct. 1939).

When a metal surface is covered with electropositive atoms (barium on molybdenum for example) to different degrees, secondary and photoelectric emission are both found to reach a maximum at the same degree of covering σ_m. The increase of secondary emission is therefore caused by a fall in the work function. The secondary emission is proportional to the degree of covering at small values of the latter, while the photoelectric emission then varies exponentially with the same. This difference is a result of the fact that the secondary electrons emitted have a much greater energy than the photo-electrons. With slow primary electrons a selective secondary emission from the adsorbed atoms can be observed.

1457: M. J. O. Strutt and A. van der Ziel: On the electric space charge between parallel electrodes taking into consideration the initial velocity and the velocity distribution (Physica **6**, 977-996, Oct. 1939). Original in the German language.

The following assumptions form the basis of theoretical considerations of the space charge between plane parallel plates (the screen grid and anode of a radio valve, for instance). There is no secondary emission. No electrons return to the space between screen grid and anode when they have once left it. Only stationary states are dealt with, while anode and screen grid have positive potentials. The velocity distribution of the electrons which enter the space in question through the screen grid is given. Since no exact solution of the differential equations can be found, they are solved numerically. The most important difference between these solutions and earlier results in which no account was taken of the velocity distribution of the entering electrons consists in the fact that the regions of the characteristic with double values become smaller with increasing spreading in the electron velocities. For the simple case of the diode Langmuir's well-known formula is obtained as a first approximation.

1458: K. F. Niessen: Curieconstant and Curietemperature of nickel alloys. (Physica **6**, 1011-1033, Oct. 1939). Original in the German language.

For nickel alloys the Curie constant and Curie temperature according to Slater's theory are considered as functions of the percentage of the metal added, particularly for the case of small amounts of this metal. In alloys of nickel with copper and zinc, electrons from the third band of the nickel as well as from that of the added metal are probably missing, while in alloys with polyvalent elements they are only missing from the nickel band.

1459: J. H. Gisolf and F. Kröger: On the proportionality of the luminescence of zinc sulphide phosphors to the irradiation at low intensities (Physica **6**, 1101-1111, Oct. 1939).

Zinc sulphide phosphors which emit several bands next to one another are found to show considerable deviations from the so obvious proportionality between the intensity of the emission bands and that of the irradiation. Because of this the colour changes appreciably with the intensity of irradiation. If it is assumed that the bands in question, not only in the form of fluorescence but also in that of phosphorescence, are exited by the same absorption process, the above phenomena are a result of the competition between fluorescence and phophorescence. The influence of temperature is discussed, and the phenomena are expressed in formulae.

1460: A. J. Heins van der Ven: Output stage distortion. Some measurement on different types of output valves (Wirel. Eng. **16,** 383-390 and 444-452, Aug. and Sept. 1939).

The disturbing effect of distortion in radio reception is discussed, together with an apparatus by which this distortion can be investigated. Measurements are described which were carried out on a circuit consisting of a pre-amplifier and different types of output valves. Modern output pentodes are found to prevent overloading in *fortissimo* passages better than triodes. Without inverse feed back the distortion in a pentode is indeed greater than in a triode, but with a power output of $^1/_3$ of the anode dissipation (*i.e.* the maximum output of a triode) it still remains below the permissible limit of 5 per cent. The greater distortion is not a result of a greater amount of third harmonic but of an extra second harmonic.

With output pentodes the distortion can be considerably reduced with inverse feed back, without causing the sensitivity to fall to a uselessly low level as would be the case with triodes. In addition to the use of push-pull connections which are not discussed in this article, the output pentode is therefore the best type of valve to use when high requirements are made of the quality of reproduction. In conclusion the behaviour of output tetrodes is also discussed. It is roughly analogous to that of pentodes. Tetrodes are, however, more sensitive to the value and the phase angle of the loading impedance than are pentodes.

1461: W. M. Hogendoorn: Ordering and testing castings. (Gieterij **13,** 142-144, Oct. 1939). Original in the Netherlands language.

In this lecture for foundry technicians the requirements are explained which can and must be made of castings in general. It is advisable to give specifications of the desired casting beforehand, in order to prevent later fruitless discussions and to force the foundry to raise the standards of reproducibility and quality of its products. Reliable measurements of the quality of a casting should be made on a part of the casting itself and not on test rods especially cast for this purpose.

1462: J. M. Stevels: New aspects on the cohesion of simple compounds. III (Rec. Trav. chim. Pays Bas **58,** 931-940, Sept.-Oct. 1939).

It is shown that the boiling points of all the halogen derivatives of methane can be calculated as the sum of the contributions of the three effects known as the London, the Keesom and the Debye effects. The three effects are studied to a higher approximation than formerly. It is found that a small correction is sometimes necessary in the old formula for the London effect. The formula for the Keesom effect seems to be correct in all cases. It may now be understood why the formula for the Debye effect does not hold so well according to the investigations of van Arkel and Snoek. In this connection the large distribution of the Debye and Keesom effects to the boiling points of the fluorine derivatives of ethane and ethene can also be understood. In combination with the refraction effect it is now also possible to predict the trend in the boiling points of isomers of the same type. No deviations can be found in the values given in the literature.

1463: J. D. Fast: The transition point diagram of the zirconium-titanium system (Rec. trav. chim. Pays Bas **58,** 973-983, Sept. Oct. 1939).

Both the hexagonal and the regular forms of titanium and zirconium may be mixed to give a homogeneous phase in all proportions. The temperature of the transition from the hexagonal closely-packed form to the cubic body-centred form is lowered by mixing. The minimum in the transition point diagram lies at an atomic ratio of 1 : 1 and a temperature of 545 °C. With this composition the transition thus takes place at a temperature more than 300° lower than that for the pure components. The transition point was determined anew for pure titanium, and the value found was 885° ± 10 °C. In the melting point diagram there is also a minimum at about 1575 °C and at an atomic ratio of 2 : 1 for titanium with respect to zirconium.

1464: J. H. de Boer and J. D. Fast: The diffusion of hydrogen through iron at room temperature (Rec. Trav. chim. Pays Bas **58,** 984-993, Sept.-Oct. 1939). (Original in German).

When one side of an iron plate is brought into contact with aqueous solutions containing a certain concentration of hydrogen ion, diffusion of the hydrogen through the iron takes place in all cases in which the solution dissolves the iron and frees hydrogen. No diffusion occurs if the hydrogen ion concentration is too low to cause such a development of nascent hydrogen. This shows that the hydrogen atoms which are formed by the chemical reaction are able to penetrate into the iron, but that the hydrogen ions in the solution are not able to do so. In agreement with this, it is found that hydrogen atoms which are formed by a hot tungsten wire in hydrogen are able to penetrate rapidly into iron plates even at room temperature, and may diffuse through the iron. In this way it is possible to evacuate an iron vessel containing hydrogen. Since the hydrogen can only diffuse through the iron from the side where it is dissociated into atoms, it will accummulate on the other side of the iron wall, and the diffusion takes place in opposition to any given hydrogen pressure.

1465: M. J. C. Strutt and A. van der Ziel: Short wave wide band amplification (El. Nachr. Technik **16,** 229-240, Sept. 1939) (Original in German).

The conditions for selectivity which the frequency characteristics of a television receiver must satisfy are compiled on the basis of the frequency spectra of the transmitters in Berlin, Paris, London and New York. The principle is given of a scheme in which vision and sound are separated from the very beginning and in which the high-frequency amplification of the vision is accomplished with the help of simple oscillation circuits as coupling elements in three stages between aerial and rectifier. Cascade amplification with identical and non-identical tuned circuits is dealt with quantitatively. It is found that the selectivity is insufficient in the first case, while in the second case the necessary conditions can be satisfied. Furthermore the changes in the input capacity and resistance are discussed and a method of eliminating them is indicated. Finally the data about noise are given and the smallest input signals which can be received without interference are deduced therefrom.

1466*: J. A. M. van Liempt and W. van Wijk: The rapid gas micro-analysis of mixtures of rare gas and nitrogen (Rev. Trav. chim. Pays Bas **58,** 964-972, Sept. Oct. 1939) (Original in German).

An arrangement is described with which it is possible to determine the composition of mixtures of rare gas and nitrogen in 10 minutes with an accuracy of 0.2% in the nitrogen content. The minimum quantity of gas needed is about 1 cc at 1 atmosphere. The analysis is carried out by means of absorption of the nitrogen by liquid lithium.

1467: E. J. W. Verwey: On the electrical double layer and the stability of emulsions (Chem. Wbl. **36,** 800-803, Dec. 1939) (Original in the Netherlands language).

The significance is discussed of the electrical double layer on the surface of particles for the stability of hydrophobic colloids and emulsions. Various reasons are given why an emulsion cannot be stabilized by the electrical double layer of its own liquid particles, while hydrophobic sols of solid particles can be stabilized by their own electrical double layer. The action of an emulgator which stabilizes an emulsion is based upon the occurrence on the surface of the liquid drops of a state like that already familiar in the case of the electrical double layer at a solid wall, where the whole potential drop occurs in the dispersing medium. Theoretical considerations of the variation of the electrical potential at an interface between two liquids are given in **1471.**

1468: F. A. Kröger: Solid solutions in the ternary system ZnS-CdS-MnS. (Z. Kristallogr. A **102,** 132-135, Nov. 1939).

The ternary phase diagram is discussed of zinc-cadmium-manganese sulphide at 900 °C. The disintegration which occurs in this system is found not to be caused by differences in the lattice constants, but by the difference in the type of bond of manganese sulphide compared with zinc cadmium sulphide.

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

Contents of Philips transmitting News. Vol. VI. No. 3/4, December 1939:

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